INEL-95/0387

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Human Performance Evaluation of Industrial Radiography Exposure Events

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CONTENTS

EXECUTIVE SUMMARY

Under Task 1 of work package E8244, "Review and Analysis of Radiography Radiation Exposure and Overexposure Events," the Idaho National Engineering Laboratory conducted a human performance evaluation of industrial radiography overexposure incidents for the U.S. Nuclear Regulatory Commission Office for Analysis and Evaluation of Operational Data (NRC-AEOD). The scope of the effort included review and analysis of historical and current events, categorization of the events in terms of human actions and contributing factors, and detailed modeling of a subset of events for additional analysis.

This report summarizes the methods, analyses, results, and conclusions drawn from the human performance evaluation. Data summaries and analysis materials are included in the appendices of this report.

The Nuclear Material Events Database (NMED) was used to identify radiography exposure events occurring between 1987 and 1994; 95 events were identified. The 95 events were categorized into eleven descriptive categories which showed that 17 events involved a survey not being performed or performed improperly; 16 involved the source not being retracted properly; and 13 events involved the dosimeter badge being tampered with or accidentally overexposed (not necessarily a human exposure). There was insufficient information available to categorize 30 of the events.

A subset of acute overexposure and acute but-less-than-overexposure events were identified for additional data collection from NRC and Agreement State regulatory offices. Sufficient information was obtained for 19 events, providing enough detail for human performance analysis of the events. Four different analysis tools were applied, each providing a different analytical focus. These tools provided complimentary analyses and a more complete picture of the facts and contributing factors associated with the radiography events. The analysis tools included: 1) operational sequence tables to outline the key human actions an interactions with equipment; 2) human reliability event trees; 3) an application of an information processing failures model; and 4) an extrapolated use of the error influences and effects diagram. Each analysis technique is described in detail in this report, and the completed analyses for the 19 events are included in the appendices. These analyses combined to indicate which subtasks of the radiography work involved errors, and how the errors might be characterized.

The data suggest that two primary types of errors occur in industrial field radiography: errors related to the use of radiation survey meters; and errors involving the set up of equipment before each shot. Errors involving the use of the survey meter are for the most part characterized by failure to execute proper procedures. Errors with equipment set up are characterized by problems with strategy or action.

Based on the analyses, suggestions were developed for how errors might be addressed, including where training, equipment interface design, or job aids might be most helpful. Sample ideas of how such considerations might be applied are discussed.

A general observation of this study was the need for detailed, consistent event reporting and data collection for better analysis of performance issues in industrial radiography. An easy-to-use guide for data collection during incident investigation might be a useful means to standardize the data collected. A brief data collection form was developed and is included in this report.

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Human Performance Evaluation of Industrial Radiography Exposure Events

INTRODUCTION

Industrial radiography is the process of using a sealed gamma radiation source, usually of iridium-192 or cobalt-60 with a typical activity range of 40 to 120 curies, to expose x-ray film images of welds and other structural elements, in nondestructive testing. Detection of structural flaws through the use of radiography can prevent hazardous conditions and the potential for serious accidents.[1]

There are two general types of industrial radiography operations: fixed site radiography, and field radiography. Fixed site radiography is usually done inside a permanent or semi-permanent enclosure that is sufficiently shielded to limit exposure to personnel outside of the enclosure. In the normal operation of the facility, the source is not exposed with personnel inside the enclosure. Access to the enclosure containing the exposed radioactive source is controlled, greatly reducing the risk of personnel exposures. This is not the case in field radiography, which is typically characterized by the use of distance (i.e., between the radiographer and the source) to attenuate radiation doses from the unshielded high activity radioactive sources. This study is limited to field radiography events.

To perform field radiography, a portable crank-out camera device is used. The camera body is internally shielded to safely store the radiation source when not in use. A drive cable, with a connection to the source, is attached at one side of the camera. A guide tube is attached to the other side of the camera. The radiographer positions the end of the guide tube at the location to be x-rayed and places films appropriately. A cranking device, located at the other end of the drive cable, is then used to extend the source out of the camera, through the guide tube to the end of the tube where the radiograph is to be taken. After each shot is completed, the radiographer must: 1) crank the source back into the camera; 2) secure it inside the camera and lock the source in the shielded position; and 3) perform necessary radiation surveys to ensure that the source has been secured. When ready to move the camera to another location, the radiographer completes all of the previous steps and should then remove the cable and guide tube before transporting the equipment to the next site. If the source is left unshielded, the radiographer and other people in the surrounding area may be exposed to levels of radiation that exceed regulatory limits and cause physical injury.

Throughout the work process, safety regulations require the use of radiation survey meters (as cited in 10 CFR 34.43b). These hand-held devices provide visual indication of the level of radiation in the area. Safety regulations also specify the use of personal dosimetry, including alarming ratemeters, to monitor radiation exposure to radiography personnel.[2]

Under Task 1 of work package E8244, "Review and Analysis of Radiography Radiation Exposure and Overexposure Events," the Idaho National Engineering Laboratory (INEL) conducted a human performance evaluation of industrial radiography overexposure incidents for the U.S. Nuclear Regulatory Commission Office for Analysis and Evaluation of Operational Data (NRC-AEOD). The scope of the effort included review and analysis of historical and current events, categorization of the events in terms of human actions and contributing factors, and detailed modeling of a subset of events for additional analysis.

This report summarizes the methods, analyses, results, and conclusions drawn from the human performance evaluation. Data summaries and analysis materials are included in the appendices of this report.

DATA OVERVIEW

The human performance evaluation task used the Nuclear Material Events Database (NMED)[3] to identify radiography overexposure incidents reported between 1987 and 1993. NMED abstracts and exposure data were used as the basis for initially categorizing the radiography events. The database contained 124 industrial radiography event records for the specified time period, with each record representing a reported overexposure or possible overexposure. In some cases, several overexposures were related to a single event. Related records were identified, resulting in a final count of 95 events involving some form of reported radiation overexposure.

Initial Data Sorting

The 95 events were initially reviewed, and the data suggested five major categories. These categories, broken into three groupings according to regulatory limits on personnel exposures, are as follows:

Exposures exceeding regulatory limits

- Acute overexposure [21 events]. Overexposure limits were exceeded during a single event.

- Exposure over time [36 events]. Reported exposure of radiation worker over a period of time (e.g., quarter, month, week).

Exposures less than regulatory limits

- Acute, but less than reportable overexposure [20 events]. Overexposure limits were not exceeded but the single event was reported.

Other

- Dosimetry overexposure [9 events]. Dosimeter badge reported as exposed while not being worn by worker.

- Uncategorized [9 events]. Reports, with insufficient or missing exposure information.

This preliminary categorization was useful for our initial familiarization with the events. Dosimetry overexposures and exposures over time could be considered together, since badges are normally processed periodically and these events are reported under the same criteria for individual exposure over a calendar quarter.[4] For our purposes, acute overexposures and less-than-reportable acute events could be considered together, as they represented the types of human performance issues of interest to this study.

Demographics

Empirical demographic data on radiographers (e.g., age, education, gender) were not available from any of the sources we contacted. One source did provide a copy of an incident database which included radiographer dates-of-birth and incident dates, from which we calculated ages for the radiographers. A sample of 126 radiographers involved in Agreement State incidents from 1987 through 1993 is represented in Figure 1. It should be noted that these data *do not* represent the radiographers involved in the events examined in this study, but *do* represent industrial radiographers as a whole. The calculated median age for the sample is 29. The positively-skewed distribution reflects a majority of younger workers (i.e., workers in their twenties) in industrial radiography. Anecdotal information collected from interviews with regulatory and licensing personnel indicated that the vast majority of industrial radiographers are male and few have formal education beyond high school or trade school.

Incidents from 1987-1994

The 95 industrial radiography incidents that were initially examined in this study were mapped over the seven years, according to their date of occurrence. Figure 2 presents the number of events reported for each year, by quarter. Regulatory Information Notices and Bulletins pertaining to industrial radiography are noted in the figure according to their date of release. No significant differences appear to exist in event occurrence over time. Similarly, it is difficult to determine the impact of specific Information Notices and Bulletins on the general frequency of overexposures. In general, the number of overexposures per quarter is quite small. Therefore, any influence affecting the number would be difficult to detect. A greater incidence of events can be seen for more recent time periods (1993-1994). This apparent rise may be due to changes in reporting practices (e.g., implementation of the NMED, increasingly rigorous data collection efforts, inclusion of event data from Agreement States since 1991) rather than an actual increase of unsafe activities in radiography.

Categorization of the 95 Events

Upon review of the 95 events, we compiled brief summaries with event descriptors. These descriptors were then sorted into eleven categories which describe the key characteristics of the events. The categories are descriptive and are not exclusive, as some event descriptions included information on more than one category. As such, the sum of the categorizations is 121. The event categories are described in Table 1. Note that the top three categories describe 15% to 20% of the events. Also, about one third (32%) of the event records did not provide sufficient information for descriptive characterization.

The matrix in Figure 3 presents the location of the different descriptive event categories within the initial sorting of five event types. It also illustrates the representativeness of a subset of data used for more in-depth analysis (as explained later in this report).

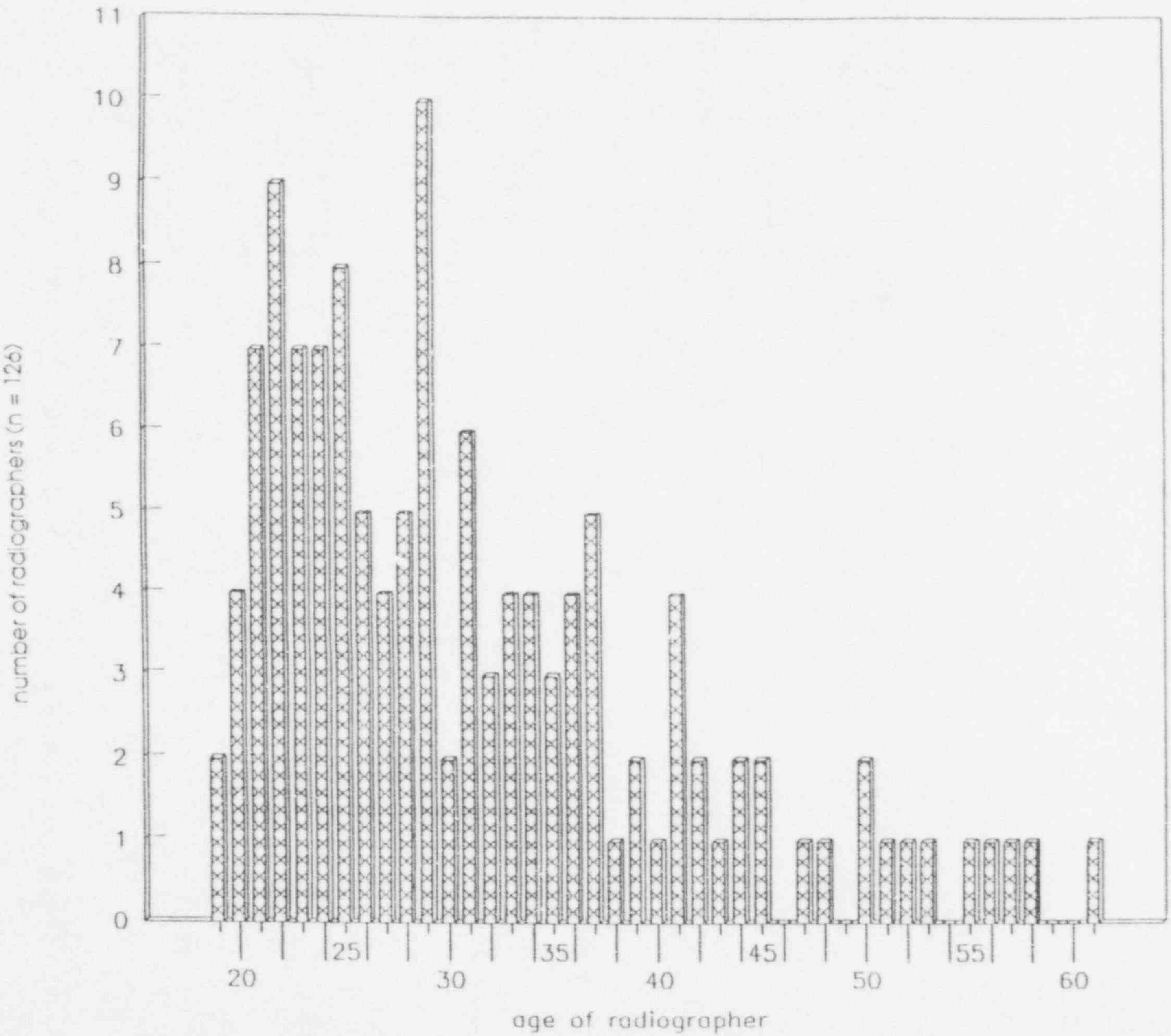

Figure 1. Sample distribution of radiographer ages

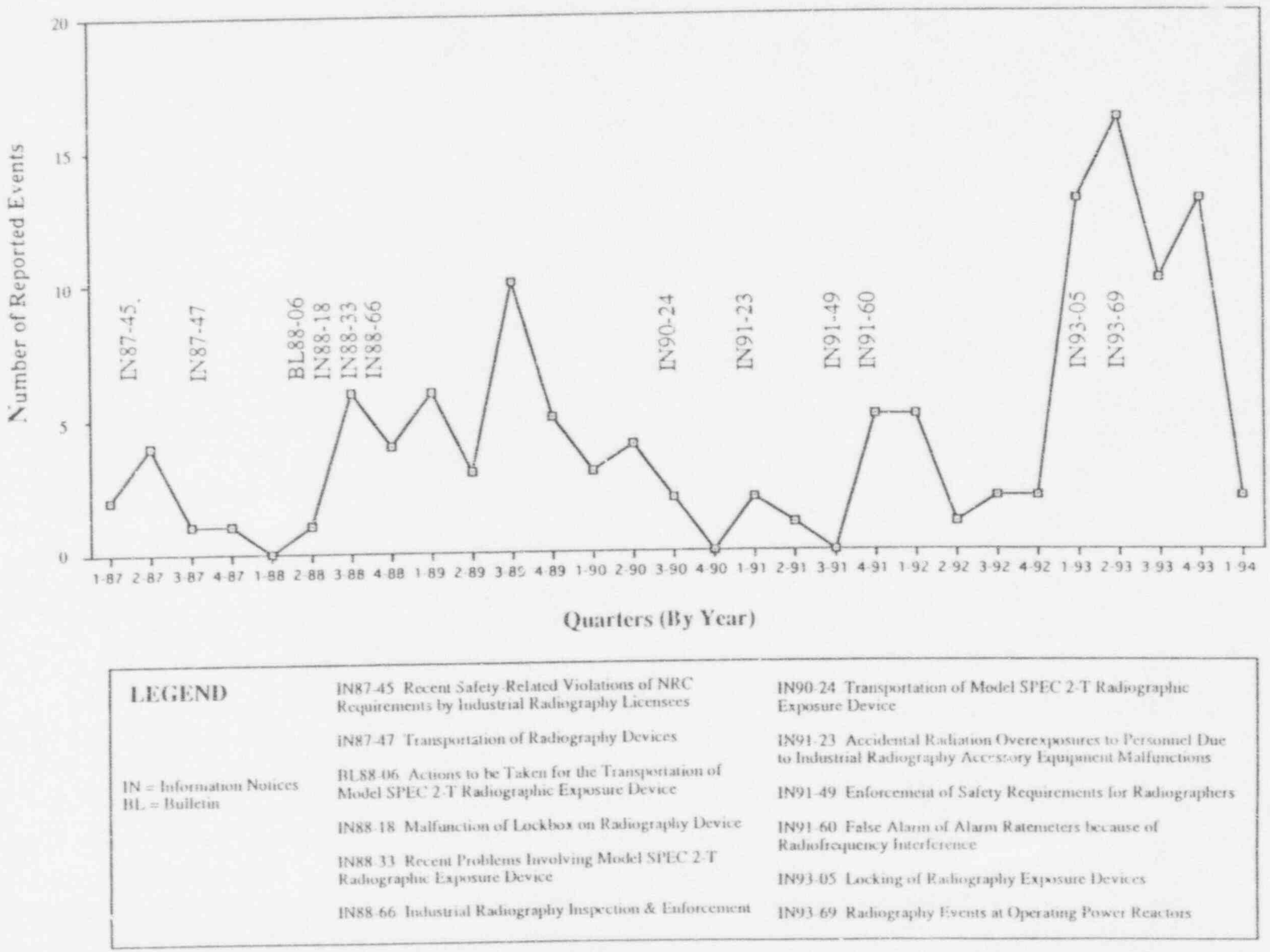

Figure 2. Industrial radiography events 1987 - 1994.

Table 1. Event categories.

Number of events (%) [n = 95]	Category	Description
17 (18%)	Survey not performed/improper survey	Radiation survey of the site and equipment was not done or was not done properly.
16 (17%)	Source not retracted	Source not sufficiently pulled into the camera (for whatever reason) to return to shielded position.
13 (14%)	Badge tampered/accidental	Personnel dosimetry badge was overexposed and was believed to have been tampered with, or the exposure to the badge was accidental and was not being worn by a radiography worker at the time.
10 (11%)	Equipment design/ failure	Apparent operational problem with the equipment or equipment failed to work properly during use.
9 (10%)	Improper/difficult source connection/disconnection	Radiation source was not properly connected/disconnected or there was some difficulty connecting/disconnecting the source drive mechanism.
8 (8%)	Source not secured/ source shifted/ locking problem	Radiation source somehow moved from shielded position due to error in securing or locking camera, or source shifted within camera during operational movement of equipment.
6 (6%)	Heavy workload	The description of the event specifically notes heavy workload as a factor in the exposure.
4 (4%)	Alarming ratemeters	The event description mentioned difficulties with alarming ratemeters, when the audible alarms were either turned off during use or not heard due to surrounding noise.
4 (4%)	Unsupervised/ not trained/ not certified	Individual performing radiography was not properly supervised or not certified or not trained.
3 (3%)	Area control problem	The event involved individuals (radiation workers or members of the public) accessing restricted or unrestricted but hazardous areas.
30 (32%)	Uncategorized/ insufficient information/	Insufficient information was provided/available to characterize the event by the above descriptors.

EVENT TYPES

DESCRIPTIVE EVENT CATEGORIES	Acute overexposure (n = 21)	Exposure over time (n = 36)	Acute but Less-than-overexposure (n = 20)	Dosimetry badge exposures (n = 9)	Other (n=9)
Survey not performed/ improper survey	• • ● ●	• • • • • •	• ● • • • •		•
Source not retracted into camera	• • ● ●		• • ● ● • • • • • •		• •
Badge tampered with or accidental exposure to personnel dosimetry		• • • • • • • • • •		• • •	
Equipment design problem or failure	• ● ● • • • •		• ● •		
Improper source connection/disconnect	● ● ● • • •		• • •		
Source not secured / source shifted	• • • ● ●		• ●		•
Heavy workload		• • • • • •			
Alarm-related	● •		• • •		
Unsupervised or not trained/ not certified	• • • ●				
Area control problem			● •		•
Uncategorized/ insufficient information	•	• • • • • • • • • • • • • •	• • •	• • • • • •	• • • • • •

• Industrial radiography event
● Event used in detailed analyses

Figure 3. Matrix of event descriptors and event types.

ANALYSIS

Once we characterized the overall set of radiography event data, we examined a representative subset of data in further detail. Our intent was to develop and apply a modeling method which would utilize the information on overexposures to help describe how human performance and equipment interactions were impacting industrial radiography operations.

Detailed data collection

In order to model a subset of overexposure events, information beyond that captured within the NMED was required. We found that the availability of additional event information was limited to the more severe (acute) exposure events. Since the amount of descriptive information for all but the acute events was limited to brief summaries, we decided to pursue additional event data for only the acute exposure and acute-but-less-than-overexposure events. We expected to find sufficient information about human performance for the acute events, and the less-than-overexposure events were of interest as they suggested possible precursors to more serious events. From our original set of 95 events from the NMED, we removed the 9 events with insufficient information, and also the 45 dosimetry and exposure-over-time events. This resulted in a set of 41 events for further consideration.

Additional event-specific information was requested from responsible regulatory agencies for the 41 acute events identified. This included data stored at each of the five NRC regional offices or with individual state agencies, as appropriate. Additional information for 26 events was received by the INEL prior to the final allowable date, which included 2 events that were not yet coded in the NMED. The data were reviewed for sufficient detail, and a final set of 19 events providing enough information was assembled for modeling. Sufficient detail (e.g., narrative on the sequence of events, personnel involved, types of actions taken, and resulting exposures to personnel) was required for the modeling approaches selected. Other information relevant to radiography, such as descriptions of radiography workers, was also sought.

Data Subset

The subset of 19 acute and acute-but-less-than-overexposure events contained 13 acute events and six less-than-overexposures. These included four cases of source not retracted; three cases each for equipment failure, source shift, connect/disconnect, and survey error; and one case each for area control, unsupervised work, and alarm-related events. This subset provides a representative sample of the overall event data set (see Figure 3). In order to best capture and analyze the information available, each of the 19 events was examined using several modeling approaches.

Modeling

To summarize performance, including human errors and equipment failures associated with each event, four different analysis tools were applied, each providing a different analytical focus. These models provided complimentary analyses and a more complete picture of the facts and contributing factors associated with the radiography events. They enabled us to look at the same data in different ways, which helped generate insights for our conclusions and recommendations.

The ability to develop complete models of the behaviors involved with the overexposures was contingent upon the type and amount of data available. Descriptive models were applied to the subset of 19 overexposure events. Modeling included: 1) operational sequence tables to outline the key human actions and interactions with equipment; 2) human reliability analysis event trees; 3) an application of an information processing failures model; and 4) an extrapolated use of the error influences and effects diagram. Frameworks for models 1, 3, and 4 were drawn from the cited reference documentation. The human reliability analysis (HRA) event trees (model 2) were based on our initial development of a generic radiography HRA tree (included as Form B in Appendix A).

Model 1. Operation Sequence Table

Descriptions of the events were first organized into an Operation Sequence Table (OST) format (adapted from Meister, 1985).[5,6] This provided a means of capturing, in summary form, the progression of human actions and interactions with equipment. This descriptive table was useful in the completion of further modeling. A sample OST is shown as Form A in Appendix A. The first column on the table identifies the radiography personnel involved as "A", "B", etc. The sequence of human actions and equipment interactions is captured in the second column. Specific equipment of interest or which contributed directly to the overexposure is listed in the third column.

Model 2. HRA Event Trees

Event trees are often used as the basis for risk and reliability assessments for human-machine system operations.[7] Using a team approach, we first identified critical subtasks of the radiography activity and then constructed the generic HRA event tree using these subtasks. A critical subtask is one that, if failed, will result in a failure of the task modeled. In modeling the radiography events, the failure criteria was that the failed subtask contributed to or resulted in an overexposure to personnel. A critical subtask may sometimes be relevant only with specific stated or implied assumptions (e.g., "failure to inspect equipment" is critical only when a detectable critical fault in the equipment is present). These subtasks were depicted at a relatively high level in the modeling of the generic radiography process. For example, the critical subtask of setting up the restricted area was not decomposed further into specific actions (subtasks) involved in setting up the restricted area. This high level modeling facilitated the development of a generic model of the process depicting important parts of the radiography activity, while avoiding site/facility/operation-specific activities. The high level modeling was also congruent with the level of detail available in many of the event reports (i.e., the modeling was data-driven). The subtasks modeled in the tree were identified as potential errors of omission (EO), potential errors of commission (EC), or potential recovery actions (REC). An omission error is characterized as failing to perform an action or skipping a step in a procedure. A commission error is characterized as performing the action incorrectly or performing the wrong action. In order to simplify the modeling, some of the subtasks identified on the tree are stated such that either an error of omission or an error of commission could apply.

Each branch on an HRA event tree represents a subtask of the activity or task modeled. The right branch of a subtask represents the failure of the subtask and is labeled with a capital letter, while the left branch represents the success of the subtask and is labeled with the corresponding lower case letter. For example, failure to perform an inspection subtask would be depicted as the right branch of the subtask and might be labeled "C," with the description "Crew fails to inspect equipment." The corresponding success of the subtask (i.e., performing the inspection) would be depicted as the left branch of the subtask and be labeled "c," with the success description implied and not explicitly stated. As noted on the tree, some of the failed subtasks create "latent conditions" for failures later in the process. For example, improper set up of equipment before a shot can lead to an inability to properly retract the source back into the camera.

Recovery actions can also be depicted on an HRA event tree. Recovery actions are actions (subtasks) that allow for the prevention or avoidance of the undesired consequence of the initial error. Recovery actions are depicted on the tree by subtask branches placed at the end of the failure branch of the initial error with a dotted line from the end of the success branch of the recovery task to the end of the success branch of the initial error. These formats are consistent with conventional HRA modeling techniques.

Following the completion of the OST, a specific HRA event tree was drawn to illustrate significant human actions and errors for each event. We then mapped the critical errors identified for each specific event onto the generic radiography event tree (Form B in Appendix A). For each event analyzed, we identified subtask failures on a copy of the generic tree with bold type. This provides a graphic qualitative depiction of the important failures of the process that occurred for the event. However, because the tree is generic, it does not necessarily depict the actual sequence of events that occurred in each specific event; it only depicts the relevant failures (in terms of the generic process) that occurred in the event.

Model 3. Information Processing Failures Model

The way that people process information can be thought of in terms of: 1) information acquisition and input; 2) decision-making; and 3) executing actions. People can fail to accomplish any one (or more than one) of these processes. It is useful to identify where failures occurred in order to better understand the motivation behind such actions and potentially determine effective corrective actions. The Information Processing Failures (IPF) model[8,9] was used to characterize the types of errors which contributed to the events. The IPF model uses the basic framework of information input, decision-making, and action execution to describe the sub-processes that people use in understanding and acting upon information provided in a specific environment or scenario. For each event, key failures were noted on the IPF diagram (Form C in Appendix A). Structural and mechanical (i.e., equipment) failures are included in the model to provide supplemental information for the analyst. In addition to equipment failures, the model highlights six error types.

- Information error (error in perception of cues)

  Information errors occur when available cues about system status are not clearly received by the operator. Information errors involve human sensory capabilities (e.g., eyesight, hearing), and existing environmental conditions (e.g., adequate lighting, noise level, relative heat or cold). In one event, a radiographer, trained to use an alarming ratemeter, was working in a high noise area and was wearing ear protection. When his ratemeter sounded an alarm, he could not hear it. This is an example of an information error.

- Diagnostic error (error in diagnosis of system status)

  Diagnostic errors involve difficulties in accurately diagnosing system status. Diagnosis relies on an understanding of the system, equipment, and the information provided. For example, when a radiographer approaches the camera with a survey meter, some low level reading is expected. If the meter reads zero, and the radiographer fails to recognize that a zero reading near the camera is a sign of something wrong with the meter, then a diagnostic error has been made.

- Goal error (failure to select an appropriate operational goal)

  Goal errors involve the selection of unreasonable or inappropriate goals given operational circumstances. A radiographer trainee intentionally left alone to complete radiography work without supervision is an example of an error in goal selection. In some cases, correct goals are maintained but other errors occur. For example, a radiographer who attempts to retrieve an exposed source is working toward a reasonable goal (i.e., to return the source to the shielded position in the camera), but may commit other errors, such as procedural or strategy errors.

- Procedure error (failure to follow proper procedures)

  Procedure errors occur when proper procedures are not followed. With the development of a routine or habit in performance of the task, proper procedures can be complied with, even without re-reading written procedures during completion of each task. Failure to follow procedures may be accidental or intentional. If the procedure error is intentional, the procedure may be difficult to enforce. For example, most modern automobiles are equipped with visual and audible cues to alert the driver to fasten seatbelts. One may choose to ignore the light on the dashboard and the beeping sound, and to not fasten seatbelts. The pieces of information ("cues") provided serve as reminders of proper safety procedure, but cannot ensure or enforce compliance. In radiography, if workers forget to use the survey meter or to lock the camera after each shot, some cue might serve as a reminder. The cues, however, could not ensure compliance if the radiographer chose not to use the meter or to not lock the camera. These are examples of procedural errors.

- Strategy error (circumvention of procedures or other inefficient strategy for accomplishing the chosen goal)

  Strategy errors involve the use of an ineffective plan or strategy for accomplishing the goal. Strategy errors are linked to problem solving or planning skills when operators come to wrong conclusions or develop incorrect plans for handling a situation. For example, in an event where the source became disconnected from the drive cable and fell from the camera, the radiographer decided to use his hand to retrieve the source and push it back into the camera port. A good strategy in this case would have been to set up and maintain a restricted area while waiting for the radiation safety officer (RSO) to arrive and retrieve the source properly. Instead, the radiographer chose a poor strategy (i.e., to manually move the source by himself) to execute the proper goal of retrieving the source.

- Action error (failure to execute steps in the work process)

  Action errors concern the failure to properly execute the intended work procedure. This involves the worker's physical motions that are necessary to complete the steps in a work process. An example of an action error in field radiography is the incorrect connection of the drive cable to the source assembly. This is a proper step in the procedure of setting up the radiographic equipment, but with the step being performed incorrectly.

Although errors that occur at different stages may result in the same outcome, the distinctions in information processing suggest different underlying causes.

Model 4. Error Influences & Effects Diagram

The final modeling tool was the Error Influences & Effects Diagram (adapted from Thatcher, et al.).[10,11] Each event was summarized in terms of the outcome (e.g., exposure amount, type), the unrecovered event (i.e., primary precursor to the overexposure), and the unsafe actions involved in the incident. Unsafe actions are those which lead to the unrecovered event. Error mechanisms which influenced the unsafe actions are also presented in the model. In our application of this model, error mechanisms describe the types of human action errors, information processing errors, or equipment failures associated with the event. These descriptors were drawn from the IPF model. The Error Influences & Effects model also captured performance shaping factors (PSFs) and corrective actions taken following the event. PSFs are environmental and personnel factors which impact the human ability to perform a task or job; ambient lighting, work space, temperature, fatigue, stress, and work experience are examples of PSFs. A sample diagram is provided as Form D in Appendix A. Note that the logic between the error mechanisms and the unsafe actions is presented with arrows, and the progression of information across the page lists first the PSFs, then the error mechanisms and unsafe actions, followed by a description of the unrecovered event. Outcome exposures and corrective actions are listed at the bottom of the page.

Detailed Modeling

The four models were applied to each of the 19 acute exposure incidents to form 19 data sets (provided in Appendix B). A summary table (Appendix C) was assembled in our analysis of the modeling results. This table lists the errors (derived from coding on the OST, event tree, and IPF models), and PSFs for each event. Also noted in Appendix C are our assumptions in modeling, and any unknown conditions or circumstances that, if information were available, might impact the way each event was modeled. Comparative analyses of the descriptive data for the 19 events are summarized below.

Event Trees

Each of the 19 events was modeled using a generic event tree with 14 main failure paths and three main recovery paths. Instead of confining the events to one main failure, they were modeled to show all important failures, allowing each event to have multiple failure paths.

The failure path with the most events was "failure to properly retract source" (53% of the 19 events reviewed). In three of the ten cases, this failure was recognized with the use of survey meters. But the other seven events in this group also involved "failure to survey." This survey error was noted in 8 of the 19 events (42%). The next most frequently noted failure paths contained almost equal numbers of events: five events (26%) had a setup that resulted in latent condition and four events (21%) involved failure to inspect or adequately inspect equipment. Three events (16%) had a setup that resulted in the source being pushed out, and three (16%) involved the failure to lock the source, resulting in a latent condition. One event (5%) involved a failure to set up or correctly set up the restricted area. Six main failure paths had no failures noted. This information is shown in detail in Appendix D.

Information Processing Failures

Failures for each of the 19 events were put into information processing failure error categories. An event could have multiple information processing failures if there were multiple errors. In addition, a specific error could be associated with more than one failure category. An example is a survey meter with a faulty reading. This could be categorized as "mechanical," due to low batteries, and also as "diagnostic" if the radiographer did not realize that a zero reading could indicate a faulty meter. In this case, we would note both an equipment failure and an information processing failure for the event.

Procedure errors were involved with sixty-eight percent of the events. Of these errors, almost half (42%) were failure to survey, with the next most common procedure error being failure to lock the camera (16%). Fifty-eight percent of the events contained errors in strategy. These were almost all unique and specific to the event (e.g., "used hands to move source back to shielded position," "looked into camera," "management planning errors"). It is worth noting here that in the three "failure to retract source" events where the survey meter was used (mentioned in the previous section), radiographers continued working after noting a high reading on the meter. This suggests errors in strategy, even though the procedure of using the meter was completed properly.

Approximately one-third of the events contained action errors (37%), mechanical errors (37%), or diagnostic errors (32%). Of the action errors, almost half (43%) were failure to fully retract the source. Over half (57%) of the mechanical errors involved faulty survey meters or bad battery contacts. Diagnostic errors were usually unique to the situation (e.g., "reboiler falsely assumed to be unrestricted area," "failed to inspect pins").

A small percent of the events contained goal errors (11%) and information errors (11%). The two goal errors involved assistants working without supervision, and the information errors were associated with sensory difficulties (i.e., problems hearing or seeing system status cues). All of the information processing failure data are presented in detail in Appendix D.

Alarming Ratemeters

Although not all of the events contained information about alarming ratemeters, the ones that did mentioned problems. These included failure to turn the ratemeter on, not hearing the alarm because of noise or ear protection, and intentionally turning the ratemeter off. None of the 19 reports mentioned successful use of the alarming ratemeter in mitigating an overexposure. However, it might be assumed that in non-event work practices alarming ratemeters are instrumental in alerting radiographers in time to avoid an overexposure incident. More detailed information regarding event-specific use of alarming ratemeters would be necessary to develop conclusions about the impact of the alarms on radiographer performance.

Performance Shaping Factors

Any indications of performance shaping factors for the events were noted during the detailed modeling. Almost a third (32%) of the events occurred at the end of the workday or around midnight. Lighting was a factor in 21% of the events, as was training. The remainder of the PSFs included factors such as working in a trench, working on scaffolding, worker wanting to speed up the job, etc. PSF information is shown in Table 2.

Table 2. Performance shaping factors.

Performance Shaping Factor	Number of events (%) [N = 19]	Examples
Shift, point of time in the workday	6 (32%)	11 hours into shift; last of 10 shots; anxious to wrap up at end of day; last shot of the workday.
Lighting	4 (21%)	Dark; low light; getting dark; poor lighting.
Training/experience	4 (21%)	Trainee; inadequate training; limited experience.
Other location conditions	4 (21%)	Working in a trench; muddy; working inside tank; working on scaffolding.
Noise	2 (11%)	Noisy; wearing ear protection prevented hearing alarm ratemeter; high noise.
Interface	2 (11%)	Source, connector, and INC hookup looked similar; camera can lock with source exposed.
Personal motivation	2 (11%)	Wanted to speed up job; turned off alarm ratemeter during paperwork to conserve batteries .
Missing feedback/ no interaction	2 (11%)	No radiation alarm in shooting cell; working alone.
Workload	1 (5%)	Heavy workload; extended work week

ADDITIONAL ANALYSES

To support use of the results of this study by the NRC and Agreement State regulators in further understanding radiography overexposure incidents, we reviewed the descriptive modeling of the 19 acute exposure events and identified:

- The kinds of errors recorded (where in the overall radiography task errors are occurring).

- Characterization of the errors (what information processing is associated with the errors).

For the purposes of this analysis, we were interested only in those events which involved exposures to radiography personnel. All but one of the events involved exposures to radiographers. We excluded the one event (which involved exposure to a non-radiation worker[a]), and examined the remaining 18 events in further detail.

Summary Of Radiography Task Errors And Error Characterization

The section that follows provides a summary of task errors and error characterization for the 18 radiography personnel exposure events. Suggestions for addressing the errors in industrial radiography are based on the results of these additional analyses.

Task Errors

The task errors (i.e., failed subtasks) that were involved in the 18 acute exposure events were identified using the HRA event tree modeling. Some events included more than one task error. Results are shown in Table 3 below.

The majority of events involved two types of errors:

- Set-up errors, including equipment set-up and failure to lock the camera (11 of 18 events)

- Radiation survey errors (8 of 18 events)

Table 3. Task errors.

Subtask	Number of events
Equipment set-up	8 events
No survey/improper survey	8 events
Equipment inspection	4 events
Failure to lock the camera	3 events
Manual retrieval of source	1 event

[a] To review the excluded event, refer to Section 13 of Appendix B.

Four events included both types of errors. Five events involved only set-up errors, and another four events were solely due to improper use of the survey meter. One event involved both failure to lock the camera and failure to adequately inspect equipment, and one involved both a set-up error and failure to lock the camera. The remainder of the 18 events involved tasks related to equipment inspection and manual retrieval of disconnected source (as indicated in the list above).

Scenarios which illustrate common performance errors in radiography might involve the following elements:

- Set-up for the shot resulted in the source being pushed out of the shielded position (e.g., the camera was not locked and the crank handle was bumped, or the camera was moved during set-up for a shot).

- Set-up for the shot resulted in a failure or inability to retract the source (e.g., a kink in the guide tube was not noticed, or the guide tube was positioned with an excessive bend, preventing retraction of the source to the shielded position within the camera).

- Exposure to the source was not detected or responded to by the radiographer due to problems with survey meter usage. This could be due to improper survey, failure to survey, or failure to properly recognize faulty survey equipment.

Error Characterization

Tasks were characterized using the IPF modeling of the 18 events. Elements of the events were characterized in addition to key task errors, which are those primarily responsible for the exposure to personnel. For example, "camera can be locked with source in exposed position" would be characterized as a Mechanical failure, while the key task error for the event, "radiographer failed to perform survey," would be characterized as a Procedure error. The different information processing failure categories are itemized in Table 4. Most events involved more than one type of error (a key error and other errors), resulting in a total number of error characterizations in excess of the number of total events.

Mechanical failures were included in the IPF to provide supplementary information about each event, but were not associated with key task errors. Goal errors (where the radiographer was working toward an inappropriate goal) were involved with two of the events, but were not key errors in the events. The five most frequently noted error categories (as associated with key tasks) are described below to clarify the distinctions between them.

Relationship between Characterization and Task Errors

The information processing failure characterizations for the subtask errors are summarized in Table 5.

As suggested in the descriptive data that we reviewed for each event, set-up errors are primarily characterized by problems with *strategy* or *action*. Survey errors, for the most part, are characterized by failure to follow proper *procedures*. Inspection task errors involve *diagnostic* difficulties.

Table 4. Error characterization.

IPF error category	Number of events in overall characterization	Number of events with key task errors
Procedure	14 events	5 events
Strategy	11 events	5 events
Diagnostic	5 events	4 events
Action	5 events	3 events
Mechanical Failure	5 events	NA[a]
Goal	2 events	0
Information	1 event	1 event

a. Mechanical failures provide information and context for the overall characterization of human errors. Key errors are associated with the specific human actions which led to the overexposure of personnel.

Table 5. Subtask errors and characterization.

Subtask	Number of events	IPF characterization (number of events)
Equipment set-up	8 events	Strategy (4), Action (3), Procedure errors (1)
No survey/improper survey	8 events	Procedure (6), Information (1), Diagnostic (1)
Equipment inspection	4 events	Diagnostic (4), Strategy (1)
Failure to lock the camera	3 events	Procedure errors (3)
Manual retrieval of source	1 event	Strategy error (1)

Addressing Information Processing Errors

Based on principles of human performance and cognition, we developed suggestions for how errors might be addressed, including:

- Where training might be most effective.
- Where equipment interface enhancements might be most appropriate.
- Where job aids might help performance.

Training can target improvements in areas of the task where *procedures, strategy*, or *diagnosis* are involved. Enhanced system/equipment interface design can address *diagnostic, information, action*, and *structural/mechanical* difficulties. Job aids that address *procedural* and *diagnostic errors* can improve performance. To help illustrate how these measures may be appropriate, each error characterization is discussed on the next page.

Procedure Errors

Training and experience will increase procedural performance. To encourage performance according to procedures, feedback (reminders) can be provided to operators in the form of "job aids." Job aids (e.g., checklists, system status cues) provide information which is easily understood and helps the worker to complete the task. This is most effective if the information is presented in immediate response to a sequence of events or a particular condition, behavior, or action. Job aids might also be incorporated into equipment design. Equipment redesign and improvement may help to reduce procedural errors by making the operations easier to complete without variance from the established procedure.

Strategy Errors

The ability to develop efficient strategies improves with experience. Training can supplement experience by providing practice and feedback on performance in controlled, "simulated" work scenarios. Training should address the circumstances under which supervision should be called for assistance in developing work strategies.

Diagnostic Errors

Training can improve diagnostic skill, and job aids can assist the workers by providing organized information that doesn't require memorization or recall. Equipment improvements can also aid in diagnosis of system status, by making the information more readily available, observed or understood.

Action Errors

Expertise in the execution of actions can be achieved with practice and enhanced with equipment design improvements that consider good human factors principles of human-machine interface design.[12]

Information Errors

With attention to the types of things which may impact performance, equipment can be modified to provide redundancy where needed to overcome environmental interference. For example, enhanced visual signals can be provided in addition to audible cues of system status when a noisy environment is anticipated.

In summary:

- Procedure errors occur in the use of survey meters, and in locking the camera after each exposure and retraction of the source to the shielded position. These errors may be effectively addressed with training on the proper use of meters and the routine of retracting the source and locking the camera after each radiograph. Job aids could also be developed to provide additional cues about system status to help workers execute procedures properly. Equipment design can help facilitate worker compliance with procedures by making procedural steps easy to execute.

- Strategy errors are made in equipment set-up and in retrieval of disconnected sources. Training in strategy development could assist workers in formulating efficient strategies for dealing with difficulties in equipment set-up and in accidental source disconnect situations. The use of supervisory personnel for assistance with strategy-related task scenarios should be included in training. Action errors are also involved with equipment set-up. These can be addressed with hands-on practice in work simulations during training.

- Diagnostic errors occur during inspection of equipment for proper functioning. The data indicate that this is particularly true in the case of survey meters. Training emphasizing how to diagnose meter status and operability could help improve performance. Equipment enhancements, such as a bright light to indicate that the meter is functioning properly, would help operators interpret equipment status.

DISCUSSION

Although the industrial radiography operation involves a fairly simple set of manual tasks, it poses an interesting scenario for human performance analysis. The analysis effort recorded in this report provided the first step toward understanding the factors influencing the progression of actions in radiography overexposure events.

Data Issues

It is important to review the results of this analysis effort in light of the limited nature of the event information available. While we were successful in collecting additional information for a representative sample of events, this sample remains small. We do believe, however, that the 19 events we modeled in detail were representative of the population of events recorded in the NMED. Additionally, anecdotal information we obtained from incident investigators indicated that the events we analyzed were consistent with historical radiographer performance data.

For a better understanding of human performance issues in the industrial radiography setting, additional information is necessary. Appendix C presents a table we used in our analytic review of the 19 acute events. This table notes the assumptions we made in coding the events, radiographer errors and equipment failures, apparent performance shaping factors (PSFs), and where information was missing. Some of the types of information we could have used but were unavailable included: the exact sequence and timing of actions in the event; equipment conditions; and radiographer knowledge of source location within the guide tube. As indicated in Appendix C, missing data necessitated the development of some assumptions in coding the events. The events would be clarified with the implementation of a program for detailed, consistent data collection targeted to addressing human performance issues.

For the data collected in this study, no specific protocol was used by all investigators. The data that were collected typically focused upon calculations of personnel exposures and regulatory violations. To understand the human errors involved in the radiography overexposure events, a data collection method is needed to provide a consistent and comprehensive source of information. In the course of this study we noted that an easy-to-use guide for data collection during incident investigations might be useful.

Based upon our understanding of the radiography task and industry practices, we developed a brief data collection form (shown in Attachment 1) to assist incident investigators in collecting human performance data from radiography events. The form provides a guide for gathering information related to the personnel involved in the incident, the description of the event, corrective actions, and the investigator's conclusions about the event cause and contributing factors.

We believe this data collection guide will be relatively easy to use. Through interviews with the personnel involved (e.g., radiographers, safety officers), the investigators will complete the sections provided on the guide, using additional paper as needed. In implementing such a data collection form, trial usage (to provide feedback for improvements to the guide) and some training or documentation (to ensure consistency in use of the guide) would be needed.

Observations on Modeling Techniques

In the course of our analyses, we developed some insights on the modeling techniques that were applied in this effort.

HRA Event Tree

The generic HRA event tree was a useful tool for representing the types of actions involved in the events. While we believe it adequately represents the generic radiography process, the tree was established prior to our detailed review of the specific events. Upon completion of our analysis, we noted several changes that could be made to the generic tree for future use. For example, there were two separate failure branches that appeared to be more closely related than depicted on the generic tree. Failure to properly retract the source ("O") can result in a latent condition where the source can't be returned ("J"), and failure to lock the source results in a latent condition ("Q") that could cause the source to be pushed out ("L"). These paths should be reviewed to see if there is a more appropriate way to model them. Additional modifications to the generic tree could increase its usefulness in cataloging successful actions, and actions which mitigate events, as well as errors.

Information Processing Failures

The IPF modeling revealed that a significant number of events involved procedure errors. It might be possible that this result was influenced by the regulatory impetus behind event investigation and data recording. Other data collection efforts could be targeted to identify more processing-related errors by emphasizing the information processing approach. With additional study, this approach could generate insights into possible remediations or interventions to target errors occurring at particular stages of information processing. This may be strongly related to issues of risk behavior and underlying cognitive processes currently under study in the transportation industry.[13]

Error Influences & Effects

The Error Influences & Effects diagrams show the logical connections between the cognitive mechanisms and the unsafe actions which contributed to the unrecoverable event (i.e., personnel overexposure). These diagrams also provide information about the factors which may have influenced worker performance. Further analysis using this modeling structure could reveal patterns of contributing factors and unsafe behavior. Data on corrective actions (also noted on the diagram) could be used in follow-up studies analyzing the impact of various types of corrective actions on subsequent performance.

Sample Ideas to Improve Performance

Based on the overexposure events we reviewed in this study, we developed some additional suggestions related to training, equipment inspection, and equipment design. This is not an exhaustive listing of issues and ideas, but simply a sample provided for further consideration.

Training for strategy errors should involve scenarios taken from actual overexposure incidents, in order to convey the message that "this could happen to you," and to teach what could have been done to mitigate the events. Training also needs to include graphic photos of radiation damage to humans. Consequences of overexposures should be dramatically shown to the radiographers to increase their awareness of the risks involved with mishandling the radiographic equipment.

There should be some kind of checklist to note that equipment inspections were performed prior to removing equipment for use. Licensees might implement a program including a designated equipment "custodian" who would be in charge of equipment inspection. Equipment would be examined by this individual before being placed in the checkout area. The custodian would check for crimped guide tubes, working lock mechanisms, survey meter battery operability, etc. This could help eliminate latent failures due to mechanical problems and difficulties with loose or low batteries in survey meters.

To the extent possible, equipment design should prevent unsafe human actions. The locking mechanism on the camera might be modified so that the radiographer would have to manually unlock the camera to expose the source, but the camera would automatically lock (by some internal mechanism that is triggered by the source) when the source is fully retracted.

Difficulties with survey meters included zero readings due to loose battery contacts in the meter. This part of the meter might be redesigned so that the batteries fit more tightly when in place. Special long-life batteries should be incorporated into the design of radiation survey devices (e.g., alarming ratemeters, survey meters) so that they don't need to be turned off to conserve energy.

Since alarming ratemeters are not always heard because of hearing protection or noisy environments, a redesign might include an additional flashing light or vibration. The vibration could be felt even through work clothes, and the flashing light, if it didn't immediately draw the attention of the radiographer wearing it, could be bright enough for a co-worker to notice. These and other equipment redesign concepts might be worthy of additional consideration.

Conclusions

In our initial analysis of the 95 events, several major sets of events were noted. Roughly one third of the events were categorized as involving procedural errors (e.g., improper survey or survey not performed, camera not locked). Interactions with equipment accounted for another third of the events (e.g., equipment design issues, source connections/disconnections). Another third of the events involved external factors, such as alarms, supervision and area control.

These results were further supported in our detailed modeling of a subset of 19 acute overexposure and acute-but-less-than-overexposure events. Procedure errors (as noted in the IPF modeling) were involved with 68% of the 19 events modeled. Of these, nearly half concerned failure to survey. There was quite a bit of overlap in strategy and procedure errors (as noted in Appendix

D), suggesting that procedural violations may be partially due to poor work strategies. The action error of failure to retract source to shielded position was noted in one third of the events, and approximately half of the events involved some structural or mechanical failure (e.g., faulty meters).

Errors in performance of industrial radiography can be characterized by the types of information processing involved in the task. The data we used in this study indicated that errors are commonly occurring in the setting-up of equipment before the radiograph and in the use of survey meters throughout the process. These errors involve diagnosis of system status, development of work strategies, and the execution of procedures. To address the errors (and the associated potential for radiation overexposures), several methods are suggested, including specialized training, equipment redesign or enhancement, and the use of job aids.

Of particular interest is the utility of survey meters in mitigating exposure incidents. While more data is needed, the information used in this study indicated that in some cases, even with the use of survey meters, radiographers are making poor choices in work strategy. Working under poor strategy can lead to dangerous conditions, as many of the events illustrate. Additional emphasis in radiographer training programs should be placed on effective strategy development and proper adherence to safety procedures.

This study provides a foundation for continuing analysis of risk and reliability in industrial radiography. Further evaluation, using detailed event information, is required to draw more conclusive insights on human performance and the interface design issues noted in this report.

ATTACHMENT 1:

Data Collection Guide for Incident Investigators

Need

In conducting this evaluation of human performance in industrial radiography, we discovered that data are, for the most part, unavailable. No specific protocol is used by all incident investigators; the data that are collected typically focus upon calculations of personnel exposures and regulatory violations. To understand the human errors involved in the radiography overexposure events, a data collection method is needed to provide a consistent and comprehensive source of information. The regulatory personnel we spoke with as part of this project expressed an interest in having an easy-to-use guide for data collection during incident investigations.

Description of the Guide

Based upon our understanding of the radiography task and industry practices, we have developed the attached data collection guide to assist incident investigators in collecting human performance data from radiography events. The guide includes questions related to the personnel involved in the incident, description of the event, corrective actions, and the investigator's conclusions regarding the event cause and contributing factors.

How to use the Guide

Investigators will take a copy of the data collection form and additional note paper with them to the event site. Through interviews with the personnel involved (e.g., radiographers, RSO), the investigators will complete the sections provided on the form, using additional paper as needed. Most questions will have short answers. The back of the form includes the generic radiography task list and space for the investigator to sketch the layout of the event site and perform exposure calculations. The subtasks associated with the incident should be checked on the generic task list. If an additional subtask is involved (i.e., one which is not listed), the investigator should write in a description of the subtask in the space provided.

Usefulness to Human Performance Analysis and in Support of the NMED

As the data repository for nuclear materials events, the Idaho National Engineering Laboratory will maintain copies of the completed incident investigation data collection forms. The NMED will use the information provided to supplement otherwise submitted event data. Additional human performance analyses will benefit from the additional data and from the consistency of information collected by investigators. Individual NRC Regional and Agreement State regulatory programs will also be able to use the data collected with the forms to conduct additional, specialized analyses of radiographer performance.

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GUIDE FOR RADIOGRAPHY INCIDENT INVESTIGATION

Personnel Involved

Age of radiographer: _____ Demographics / NMED DEMOCODES (check all that apply):

❑-Female ❑-Male ❑-Physically Handicapped, Deaf ❑-Physically Handicapped, Other ❑-Non-English Speaking

Title/level of worker (trainee, assistant, radiographer, supervisor, RSO): ________________________

Formal education completed: did not complete high school/GED❑, high school/GED❑, technical/trade school❑, college❑, other ________________________

Years of experience as radiography worker: _____ Years working with current licensee: _____

Amount and type of training completed: ________________________

________________ Certifications: ________________________

Event

Date of event: _____/_____/_____ Time of event: __________ am❑ pm❑

Hours worked since beginning of shift at time of event: __________

Work schedule (shift duration, number of shifts in work week): ________________________

____

Crew familiarity (how many times have they worked together): ________________________

Where work was conducted (inside, outside, type of structure, etc.): ________________________

Environmental conditions (lighting, noise, etc.): ________________________

Equipment involved (make/model/manufacturer/components/parts): ________________________

____

What happened (sequence of pre- and post-exposure activities): ________________________

____

Why sequence of events occurred (workers' accounts including what they were thinking): ________________________

____

Existence of alarms or warnings (were alarming ratemeters used?): ________________________

Licensee corrective actions (describe) ________________________

____

On Reverse side of this form

❑ Generic Radiography Task List (check appropriate tasks) ________________________

❑ Sketch of site layout (including equipment and personnel) and exposure calculations ________________________

Investigator Conclusions

Contributing factors (descriptive terms) ________________________

Cause of the event (descriptive terms) ________________________

Generic Radiography Task List

(Check all that apply to the event)

- ❑ Crew fails to properly inspect equipment/set-up for workday
- ❑ Crew fails to plan work
- ❑ Crew fails to correctly plan work
- ❑ Crew fails to inspect equipment
- ❑ Crew fails to adequately inspect equipment
- ❑ Crew damages equipment during transport
- ❑ Crew loses equipment during transport
- ❑ Crew fails to lock source for transport
- ❑ Crew fails to set-up restricted area
- ❑ Crew incorrectly sets-up restricted area
- ❑ Set-up results in latent condition (source can't return to shield)
- ❑ Failure of post-xray survey to detect source exposed
- ❑ Crew set-up results in source being pushed out of shield
- ❑ Failure of continuous pre-survey to detect source exposed
- ❑ Crew fails to properly time exposure
- ❑ Crew fails to properly retract source
- ❑ Post survey fails to detect improperly retracted source
- ❑ Crew fails to lock camera, results in latent condition
- ❑ Other (describe) ______________________________

Site Layout Sketch and Exposure Calculations

Appendix A

Blank Forms

Operational Sequence Table (Example form)

person	operation	equipment

person = individual(s) involved in the action

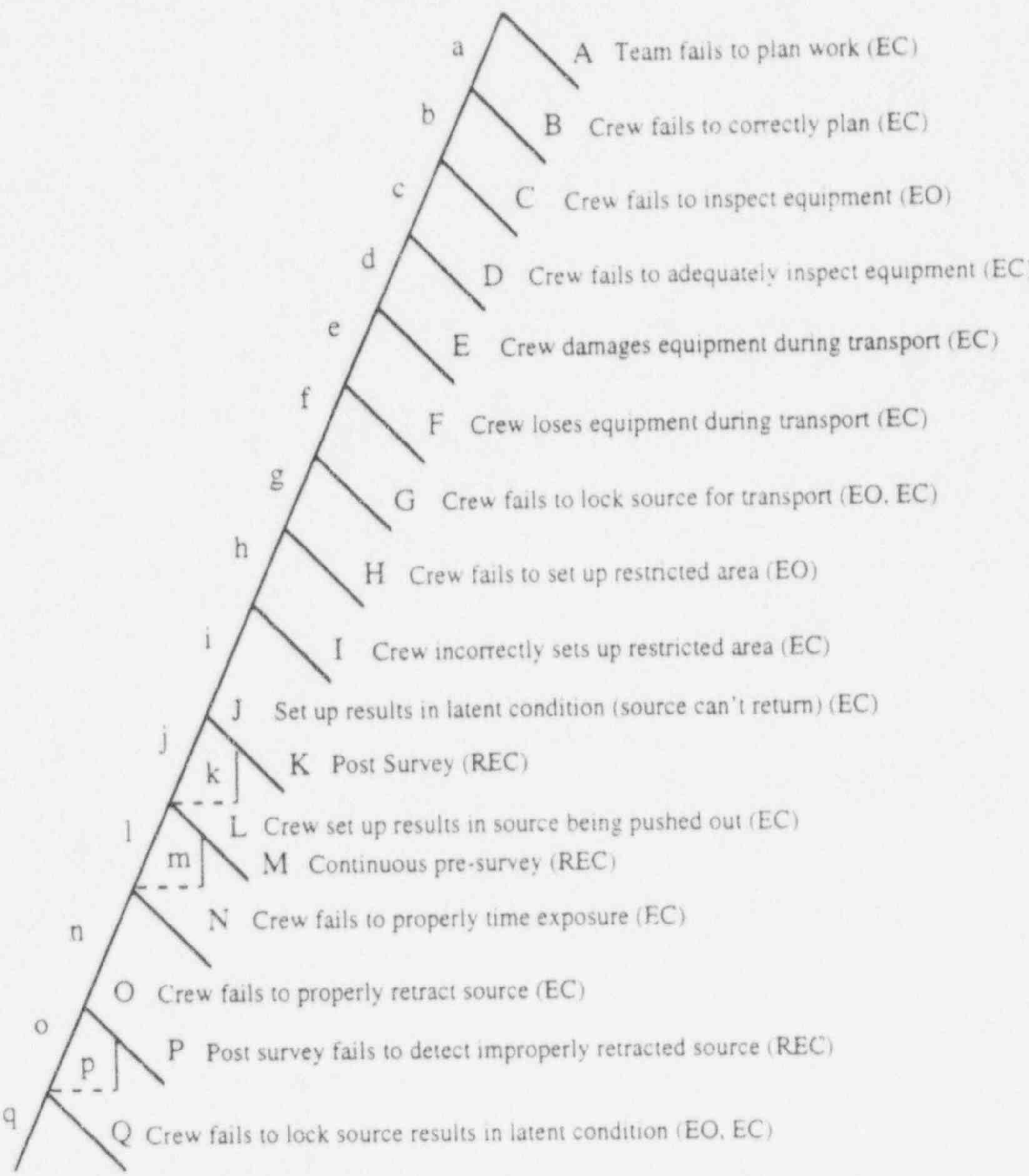
operation = action that was performed, actions are listed in sequence

equipment = pieces of equipment

Any additional information is noted at bottom of OST.

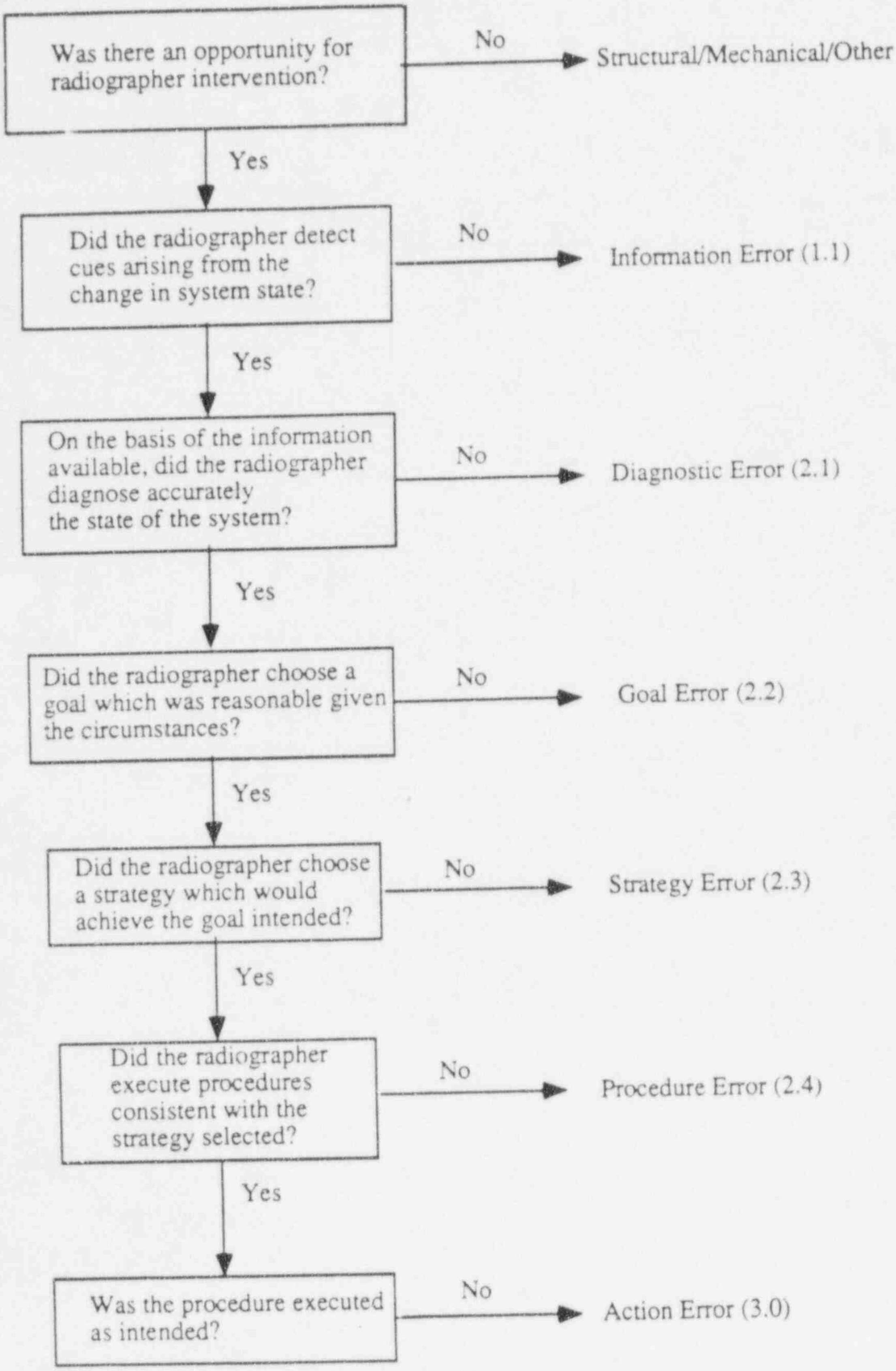
Form A. Operational sequence table.

Event Tree for Generic Radiography



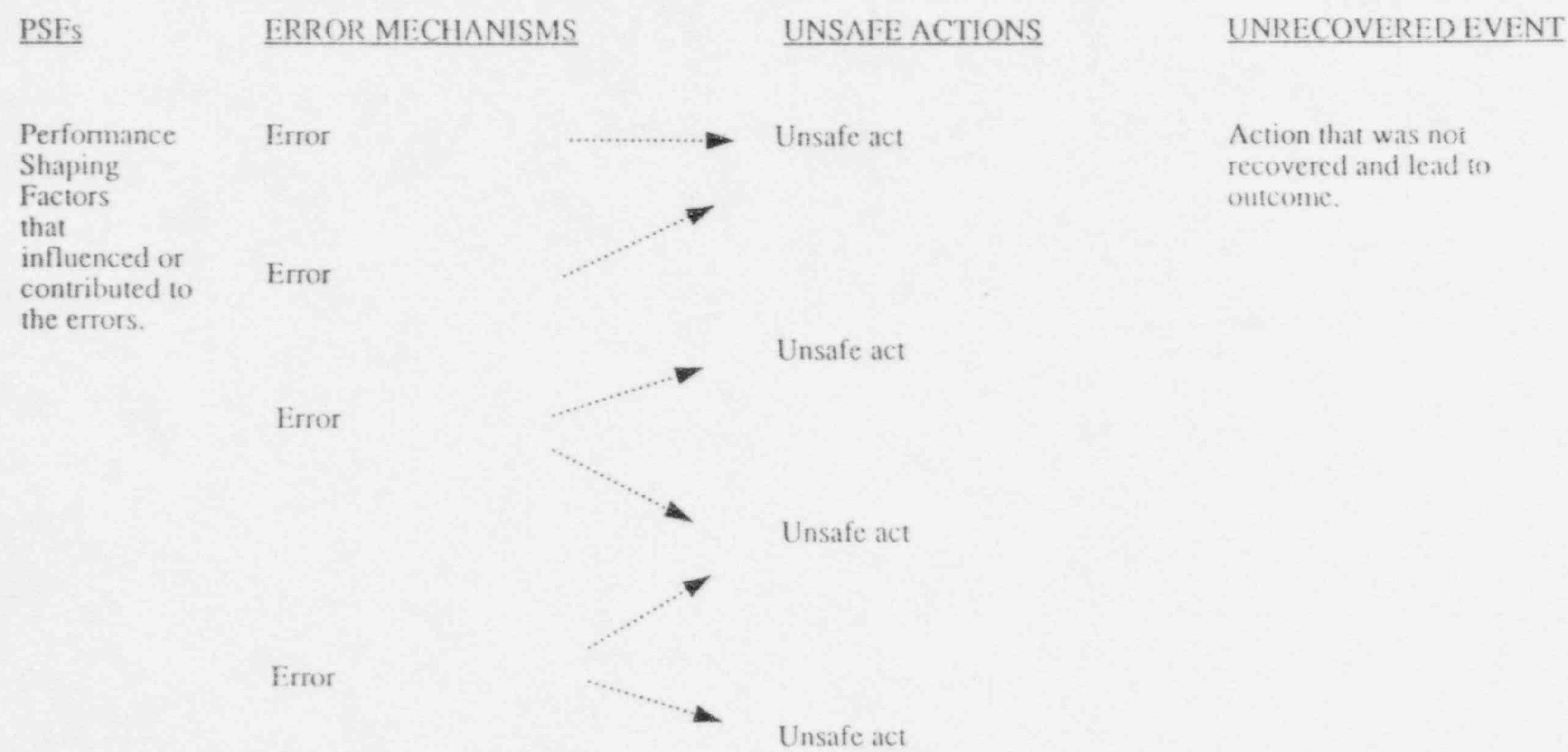
Form B. HRA event tree.

Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Form C. Information processing failures model.

Error Influences & Effects



OUTCOME

Personnel exposed

- exposure

CORRECTIVE ACTIONS

Corrective actions, as described in writing within the event report.

Form D. Error influences and effects diagram.

Appendix B

19 Acute Event Analyses

Appendix B
Section 1

1

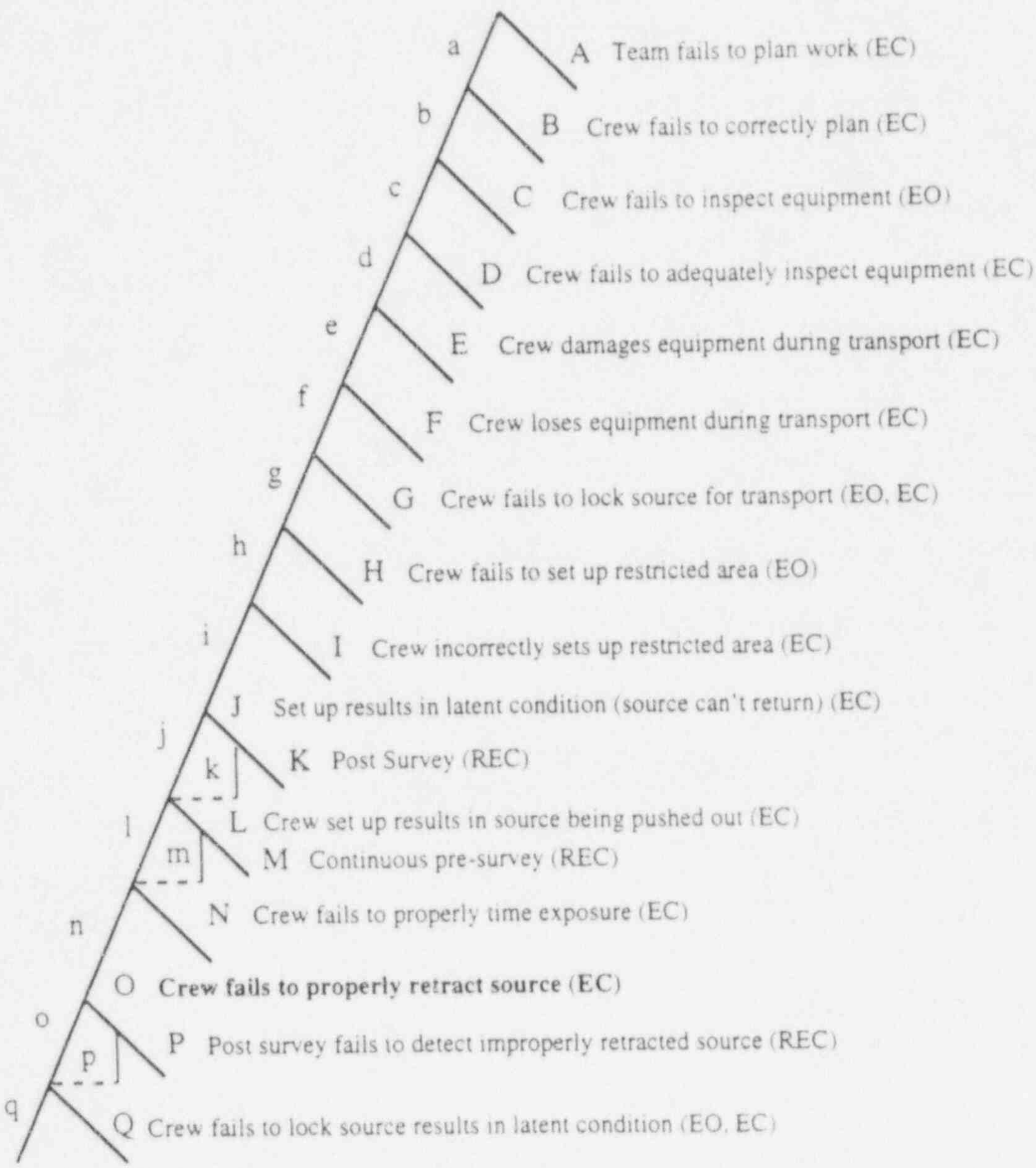
person	operation	equipment
A, B	radiographers (A, B) set up camera	
A, B	posted signs	
A	made first exposure (camera felt sticky)	
B	cranked in source, had trouble	
?	survey meter pegged out	survey meter
A	tried to crank back source	crank, source
A	tried several times to crank back source	crank, source
A	directed B to get other survey meter to ensure the first was working properly (was now dark)	
A	put lead across camera for shielding	
A	recharged dosimeter (had 190 mrem)	
A	repositioned lead	
A	read another 185 mrem on dosimeter	
A	sent B to get onsite inspector (C)	
B	got onsite inspector (former radiographer)	
A	told B to rope off larger area	
B	roped off larger area	
A	asked onsite inspector to call RSO	
C	called RSO and suggested he stay by phone rather than drive over	
B	moved to within 50 ft distance, within shouting distance	
C	called RSO back to tell him things were under control	
A	attempted to remove source from camera with channel locks (source fell from source tube into mud)	
A	reached down, picked up source, and replace in camera (very dark outside, source was sticking out about one inch)	
A	placed lead around camera	
A	recharged dosimeter (had picked up 195 mrem)	
A	took survey readings (high readings)	survey meter
A	saw that wrong end of source was in camera	
A	picked up center of wire so wouldn't touch either end (?)	
A	tried to push source into camera but wouldn't go back in	camera, source
A	pulled source out with channel locks and placed under lead	
A	removed lock box	
A	removed lead	
A	picked up source with channel locks	

A	put source into camera	
A	saw pigtail out back of camera	source
A	replaced lock box	
A	pushed locking mechanism into place	
A	shut down work area	
A	placed camera in cage with note "do not use camera"	
A	called RSO and explained what happened	
?	additional information on checking camera and returning sources to supplier and medical assessment	

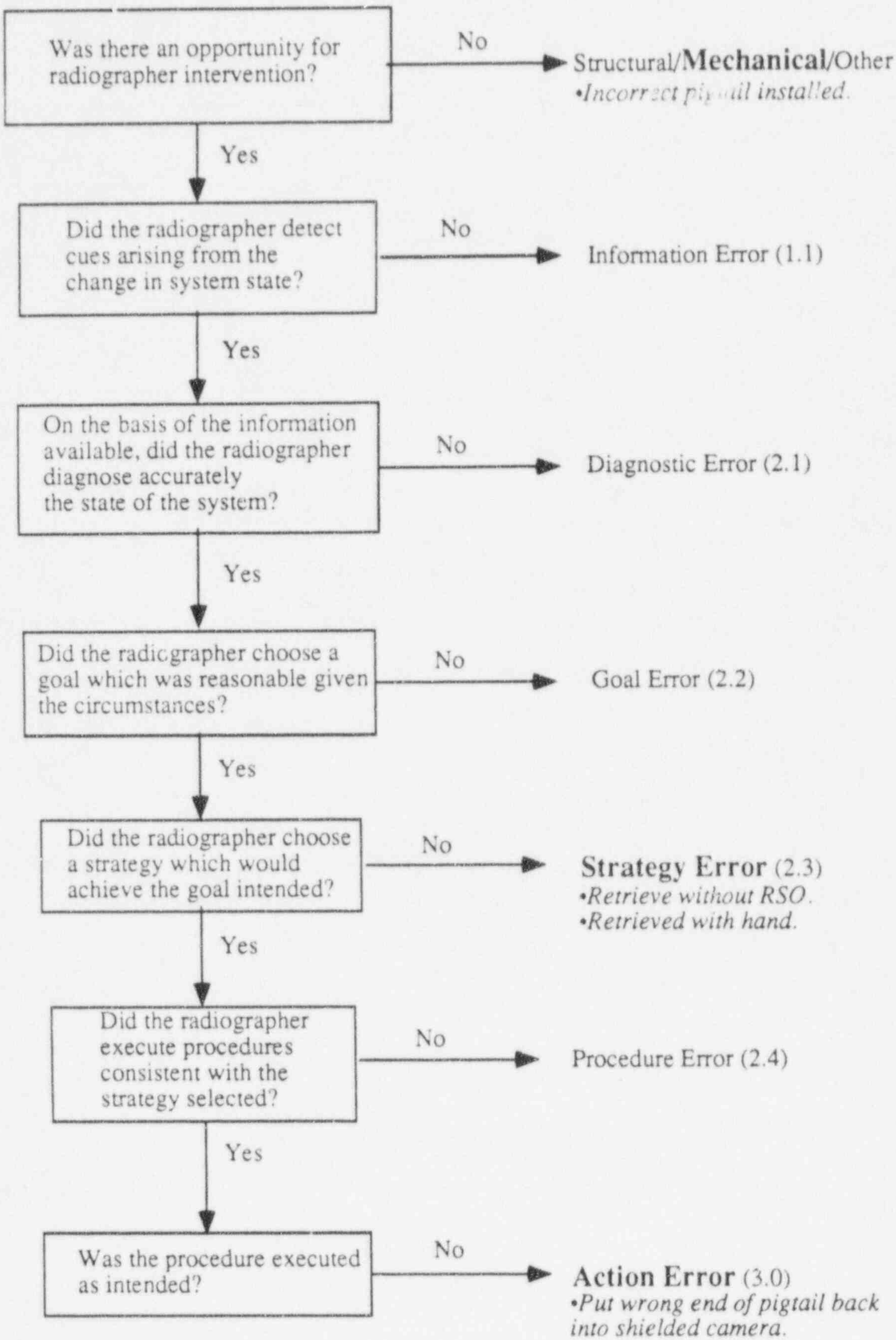
* root cause - using Model 32 source instead of Model 22 (difference in length of approximately one inch and flexibility of cable), meant to be used in different camera

* some question as to the accuracy of the account

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982) 1



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Dark • Working in trench • Muddy area	Structural/Mechanical	Incorrect source pigtail used	Source fell from camera and was manually retrieved by radiographer.
	Strategy Error (circumvention)	Failed to have RSO recover dropped source Removed guide tube without survey Picked up source with bare hand	

OUTCOME

Radiographer exposed

• 1500 REM extremity

CORRECTIVE ACTIONS

Regulatory agency orders given to licensee.

Appendix B
Section 2

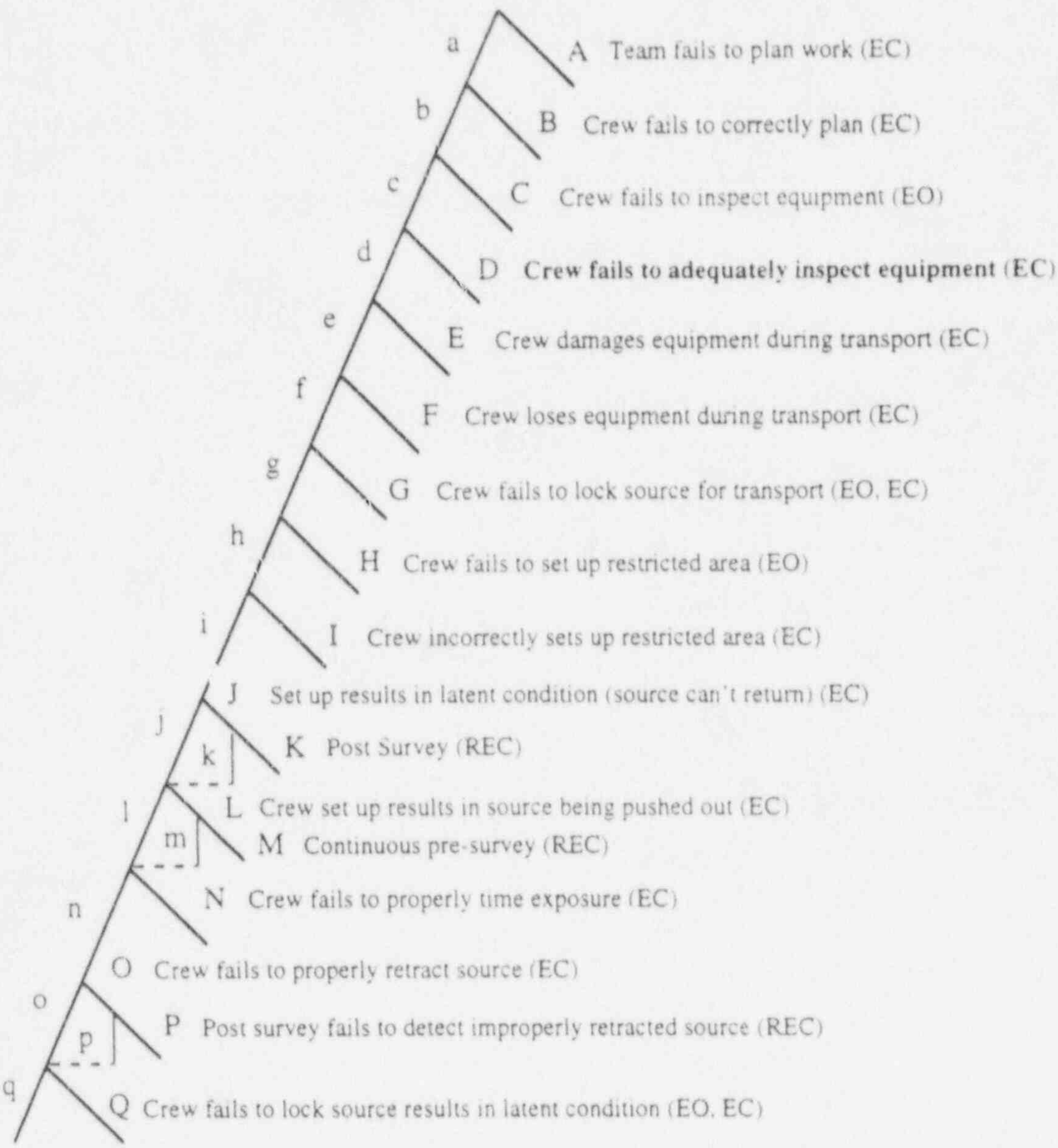
2

person	operation	equipment
A, B	radiographers (A, B) had taken 30 radiographs	
A, B	proceeded to darkroom and developed film	
A	took off film badge and attached it to clipboard	film badge
A, B	made one reshoot, surveyed camera, returned to truck (survey reading normal)	survey meter, camera
A, B	went to next reshoot area	
A	went to back of truck	
B	stayed in truck cab	
A	surveyed (meter showed source in shielded position)	survey meter, source, camera
A	placed coiled crank out cable around left arm with cable hooked to camera	crank out cable, camera
A	picked up camera with right hand	camera
A	took two steps backward (cable disconnected and fell from camera to ground)	cable, camera
A	stepped back to truck	
A	placed camera on tailgate	
A	dropped crank out cable from left arm	
A	picked up crank out cable 3-4 ft from end (low light conditions)	
A	worked way up cable with right hand	
A	believed he held end of crank out cable between thumb and index finger	
A	brought end close to face (about six inches) to look at it	
A	realized he was holding source cable	
A	dropped source and cable onto ground	
A	yelled to B that source was exposed	
A, B	immediately left area	
A	noticed survey meter offscale	survey meter
A	noticed dosimeter offscale	dosimeter
A	called RSO, who then returned source to shielded position using long handled pliers*	

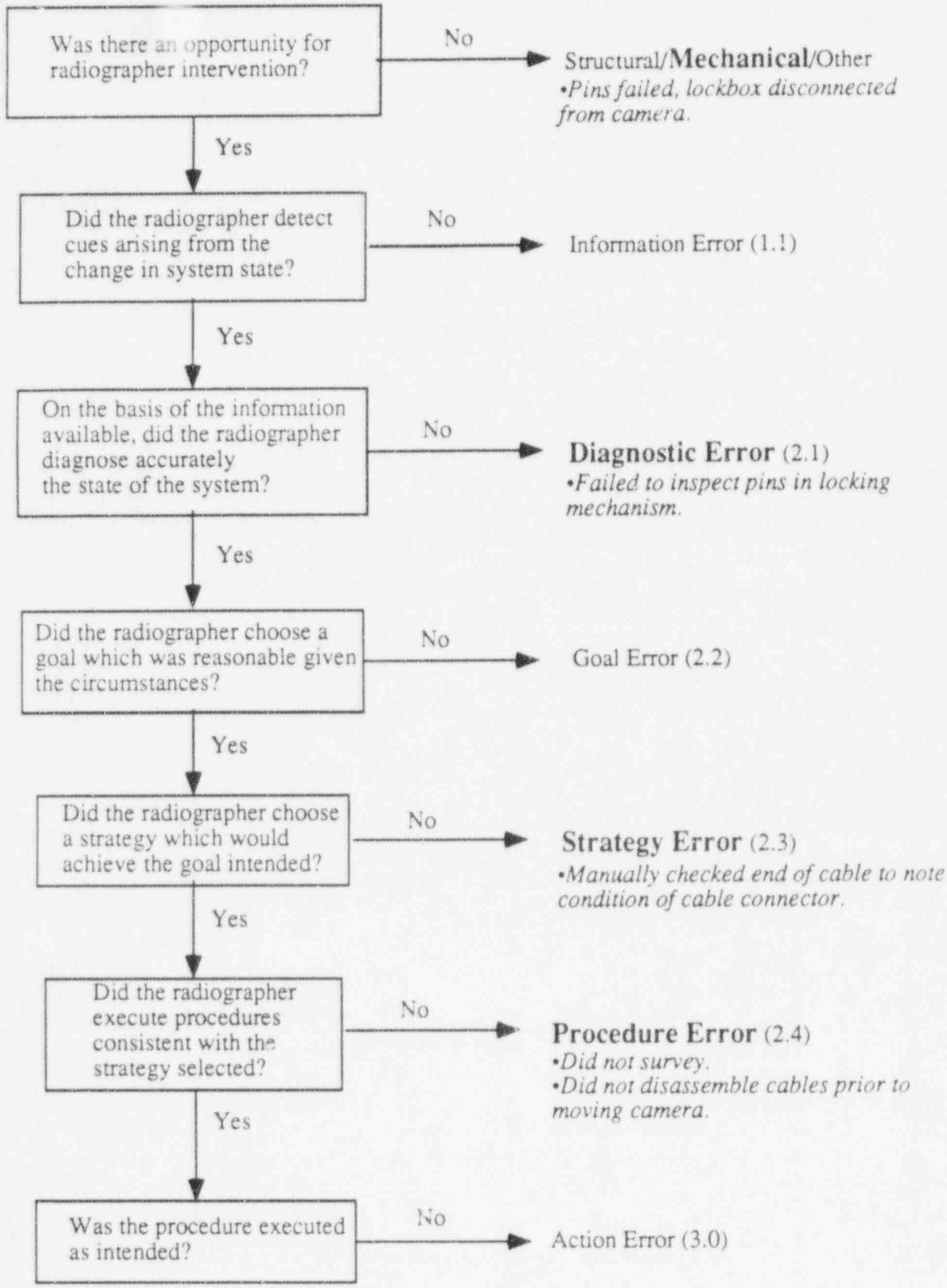
* 2 roll pins hold crank out assembly in place; the bottom pin was missing, the side pin appeared to work its way out and allowed assembly to come out

* "A" recommended that, in subdued light, he would survey all equipment first before picking it up.

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982) 2



Error Influences & Effects

PSFs

- Low light
- Source, connector and hookup look similar

ERROR MECHANISMS

Structural/Mechanical

Diagnostic

Procedure

Strategy Error (circumvention)

UNSAFE ACTIONS

Insufficient inspection of equipment

Did not remove cables from camera before movement

Manually checked end of cable without surveying

UNRECOVERED EVENT

Pins holding locking mechanism onto camera failed when equipment was lifted onto the truck, exposing the source.

OUTCOME

Radiographer exposed

- 1600 - 2000 REM fingers (calculated worst case)

CORRECTIVE ACTIONS

Radiographer not allowed to work in radiation area.

Personnel informed that failure to wear film badges will result in termination.

Letter explained event, distributed to company.

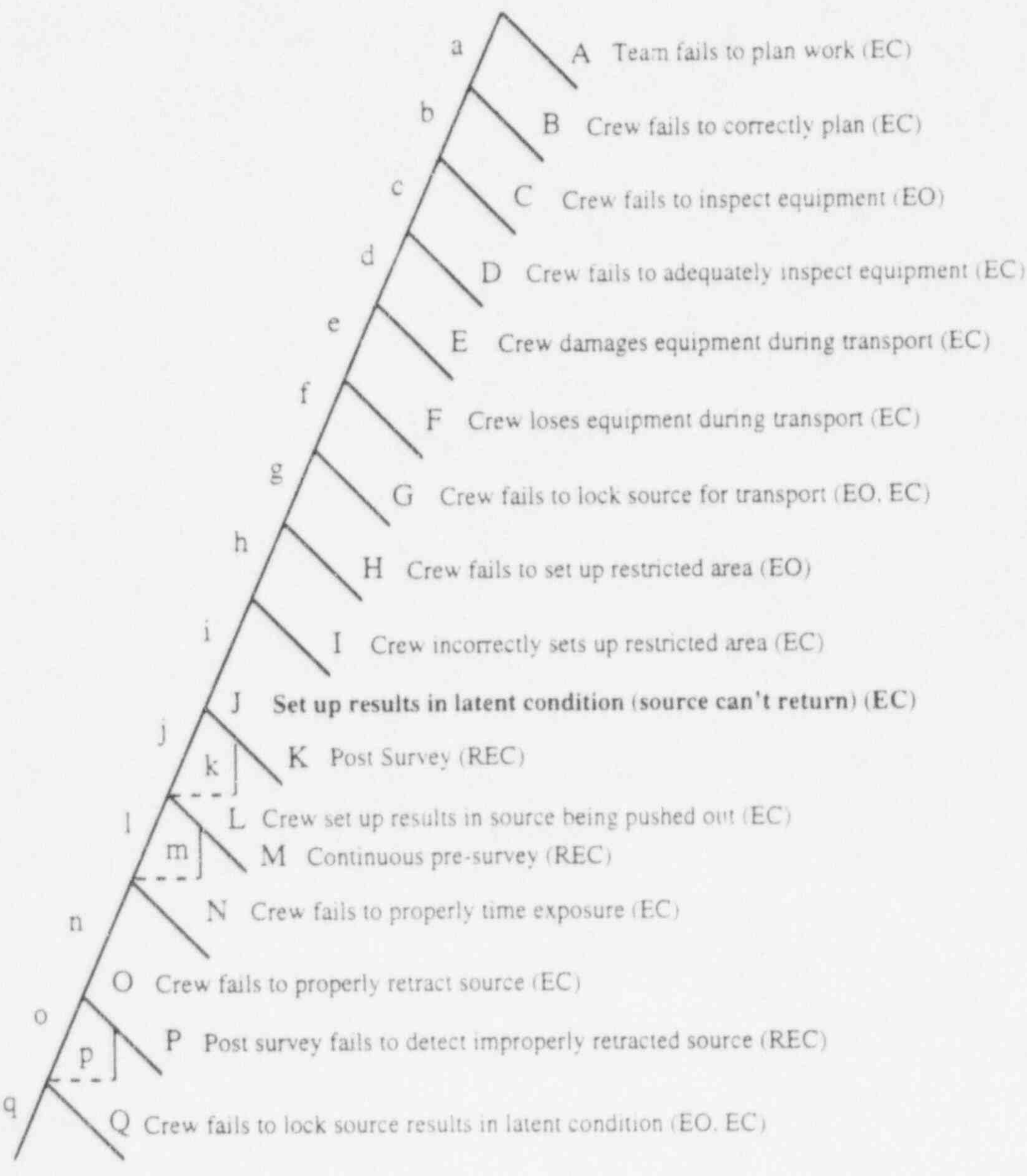
Appendix B
Section 3

3

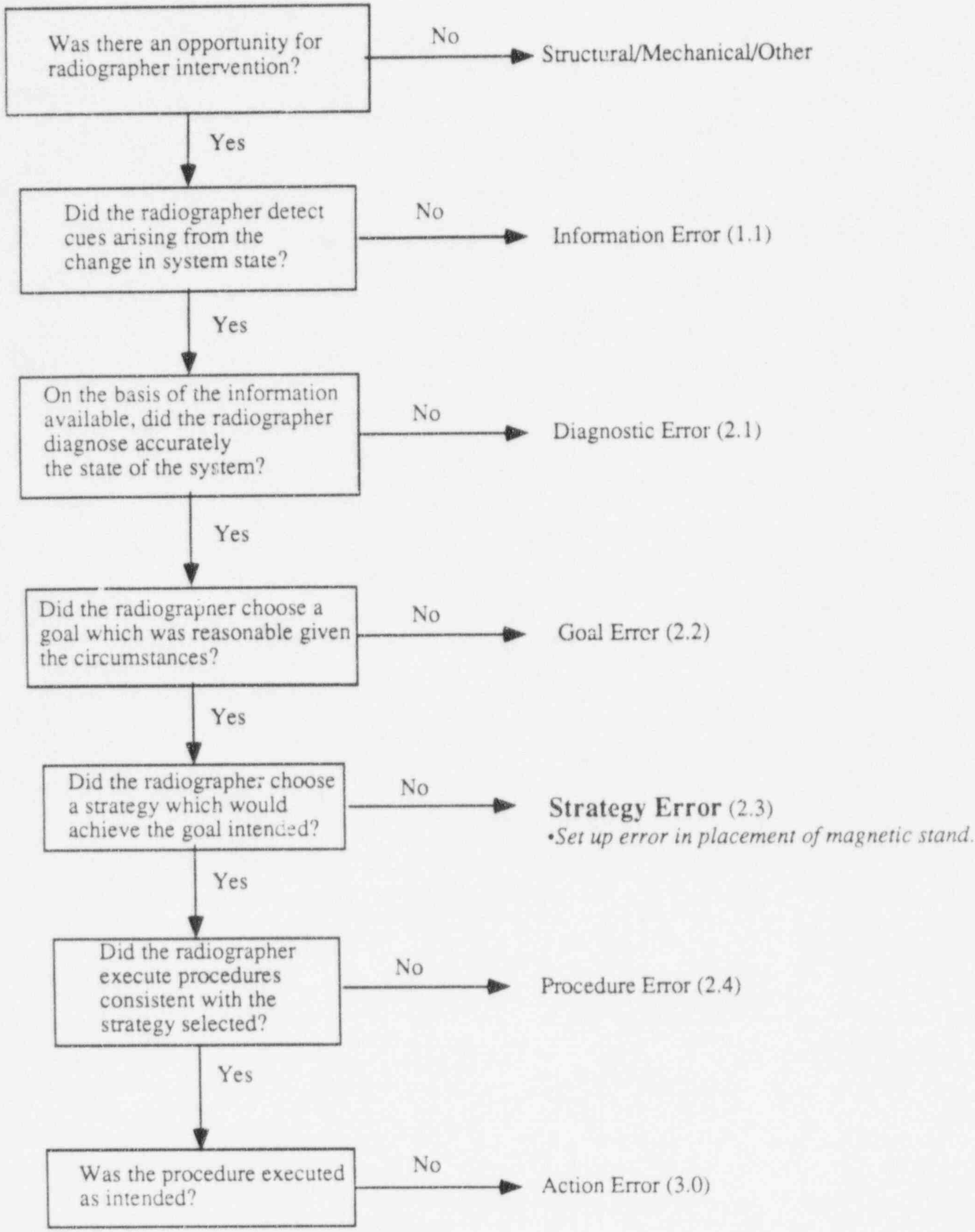
person	operation	equipment
?	placed camera on 5 gal. bucket	exposure device
B	assistant (B) was watching the radiation area and told radiographer (A) that it was clear	
?	magnetic stand was on top of tank	magnetic stand
A	cranked out source	
A	replied that he was shooting	
B	survey meter showed shot had begun	survey meter
B	heard loud noise in tank (magnetic stand had fallen about 5 sec. after crank out)	magnetic stand
B	saw A cranking back source	
A	yelled that stand had fallen	
B	saw survey meter reading indicating radiation still in area	survey meter
A	signalled source hung up and exposed	
B	roped off larger area	
B	went into tank and saw stand on ground with guide tube around it	
B	held camera	
B	straightened guide tube	
A	tried to crank in	
A, B	noticed dent (crimp) in source tube	source tube
A	notified company and customer RSO	
B	secured area	
C	arrived at site about half an hour later	
C	verified radiation zone secured by visual surveillance and barricade tape	
C	decided to use pliers to straighten crimp	
C	squeezed crimp	
C	attempted to retract source (source stuck at crimp)	source, guide tube
C	placed lead shot over source	
C	90 mrem from dosimeter	dosimeter
C	squeezed crimp with pliers for 1 second	
C	returned source to collimator	
C	directed A and B to place concrete bags over collimator	
A, B	put concrete bags on collimator	
C	discussed situation with A	
C	decided to cut guide tube and ream out source tube	
C	re-entered area (survey meter reading 400 mrem/hr	survey meter

C	cut guide tube with pipe cutters	
C	reamed out crimp with screw driver	
C	taped guide tube together	
C	returned to crank and attempted to retract (source got stuck again and taped guide tube separated)	crank, guide tube
C	manually pushed source into collimator	
C	pocket dosimeter offscale	dosimeter
C	added additional lead sheet on side of concrete bags, which reduced readings to 200 mrem/hr	survey meter
C	re-entered area	
C	cut out crimp in guide tube	
C	taped together guide tube	
C	retracted source	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Working inside tank	Strategy Error →	Placed guide tube directly under magnetic stand	Magnetic stand fell, crimping guide tube, resulting in failure to retract source.

OUTCOME

Exposure to RSO during retrieval

- 5 REM extremity
- 0.4 REM whole body

CORRECTIVE ACTIONS

Purchase new magnets.

Do not place guide tube or camera in path of possible fall.

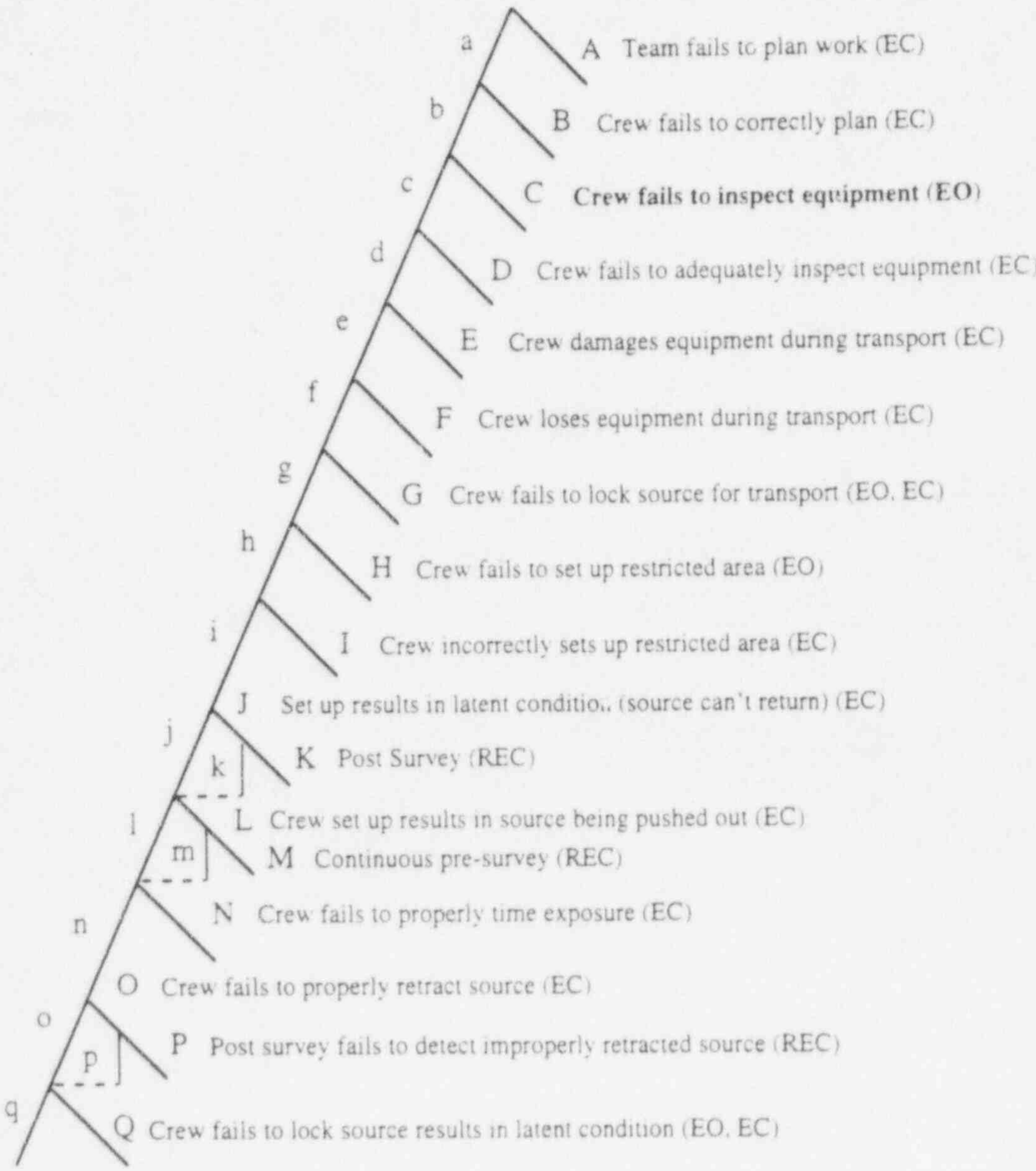
Appendix B
Section 4

person	operation	equipment
B	move equipment from storage to setup area	
A	preparing film identification	
B	inspected equipment	
B	connected crank	
B	connected guide tube	
B	secured restricted area with ropes & signs	
A	checks exposure device	
A	checks lock on exposure device, turn key to unlock, rotated selector ring to operate, tried to rotate ring to lock (selector ring did not rotate to lock)	exposure device, selector ring
A	wiggled control cable	
A	moved to hand crank	
A	moved crank toward exposure	
A	moved crank toward retract (handle rotated 1/4 turn)	exposure device, crank
A	felt solid stop	
A	moved to exposure device	
A	tried to lock device, but would not rotate to lock	exposure device
A	noticed survey meter on floor in front of device pegged on 100 mr scale	survey meter
A	grabbed meter	
A	switched to 1000 mr scale and observed maximum reading on scale	survey meter
A	moved back to crank handle	
A	moved crank toward exposure	
A	moved crank toward retract (handle rotated 1/4 turn)	exposure device, crank
A	moved to exposure device	
A	tried to lock device (did not rotate lock)	exposure device, lock
A	moved back to crank	
B	returned to crank area	
A	informed Rad. B of problem	
B	surveyed barricade ropes (no high radiation at barricades)	survey meter
A	instructed Rad B to move barricade ropes an additional 20 ft.	
B	asked electricians to leave area	
B	moved barricade ropes	
A	returned to crank	
A	moved crank toward exposure	
A	moved crank toward retract (camera did not lock)	exposure device
A	moved to exposure device	

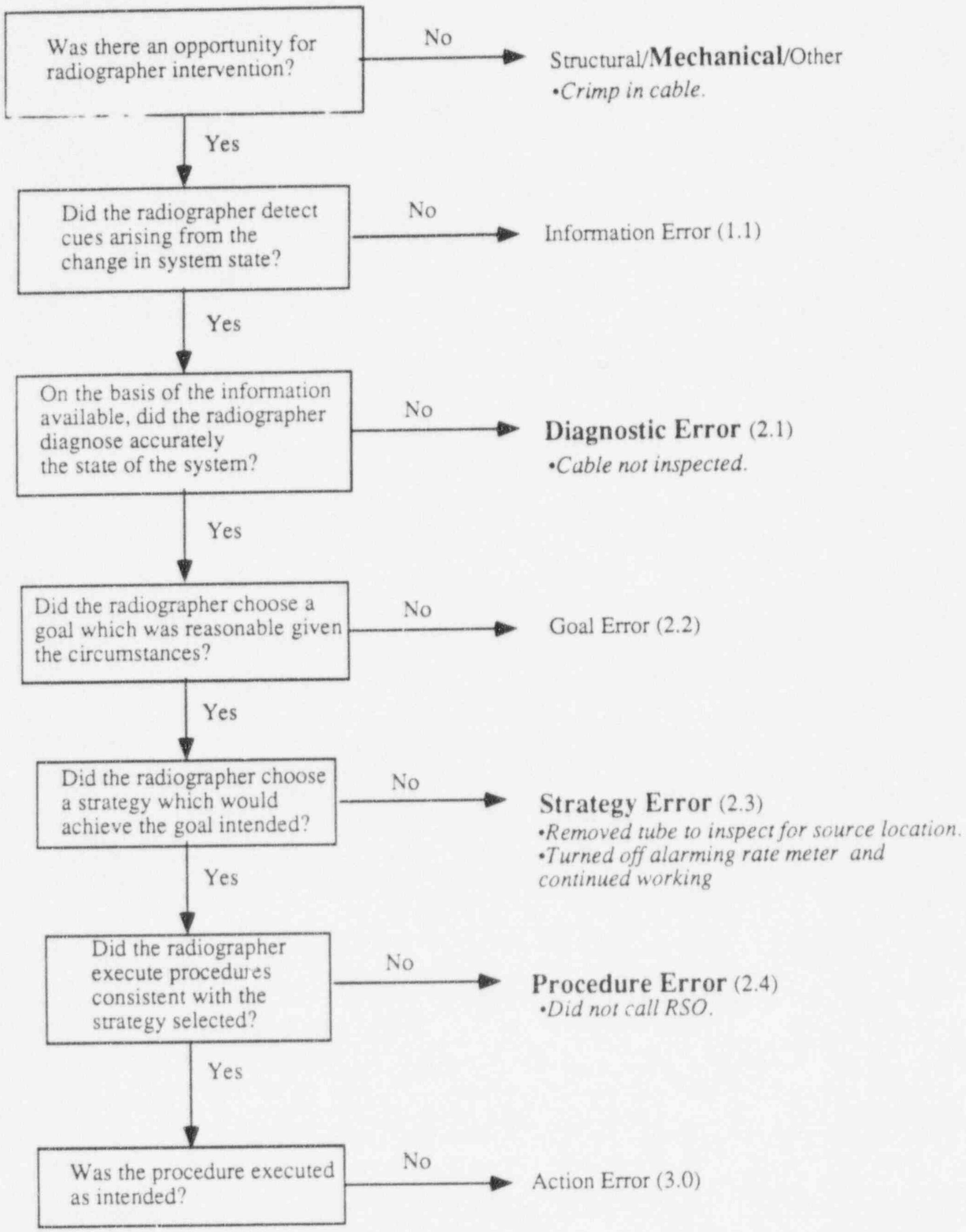
A	took survey (showed high radiation	survey meter
A	leaned forward	
A	looked at guide tube	
A	saw not abnormalities	
A	moved to position halfway between exposure device & crank	
A	moved to exposure device	
A	knelt down behind & to right of exposure device	
A	slid survey meter in front	
A	leaned over projector	
A	tried to remove guide tube with finger tips, but connection threaded too tight	exposure device
A	removed hands & leaned away	
A	leaned forward	
A	used fingers & palms to loosen nut	
A	removed hands & leaned back	
A	leaned forward	
A	used fingers & palms to remove guide tube	
A	grabbed survey meter	
A	leaned forward	
A	saw source out of device, positioned in connector nut	
A	moved to crank handle	
A	retracted source	
A	locked exposure device	
A	surveyed exposure device (readings normal)	survey meter
A	inserted safety plug	
A	surveyed guide tube	
A	checked dosimeter ("A" dosimeter off-scale)	dosimeter
B	returned from moving barricades	
A	told Rad B that incident was over	
B	checked dosimeter ("B" dosimeter reading of 6 mr)	survey meter
A	informed customer	

...more aftermath follows

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982) 4



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
(Unknown)	Structural/Mechanical	Radiographer B did not detect bent drive cable during inspection	Radiographer attempted to locate unretrieved source without RSO.
	Diagnostic Error		
		Radiographer A reached in to disconnect guide tube three times	
	Strategy Error		
		Turned off alarming ratemeter and continued working	
	Procedure		
		Did not call RSO to retrieve source	

OUTCOME

Radiographer (A) exposed

- 1107 REM hands

CORRECTIVE ACTIONS

Bent drive cable connector replaced, other control cables inspected (none found faulty).

Training on emergency procedures and alarming ratemeters.

Increased management emphasis on equipment checks before use.

Review & assessment of incidents to stress safety.

Written report of event for all radiographers.

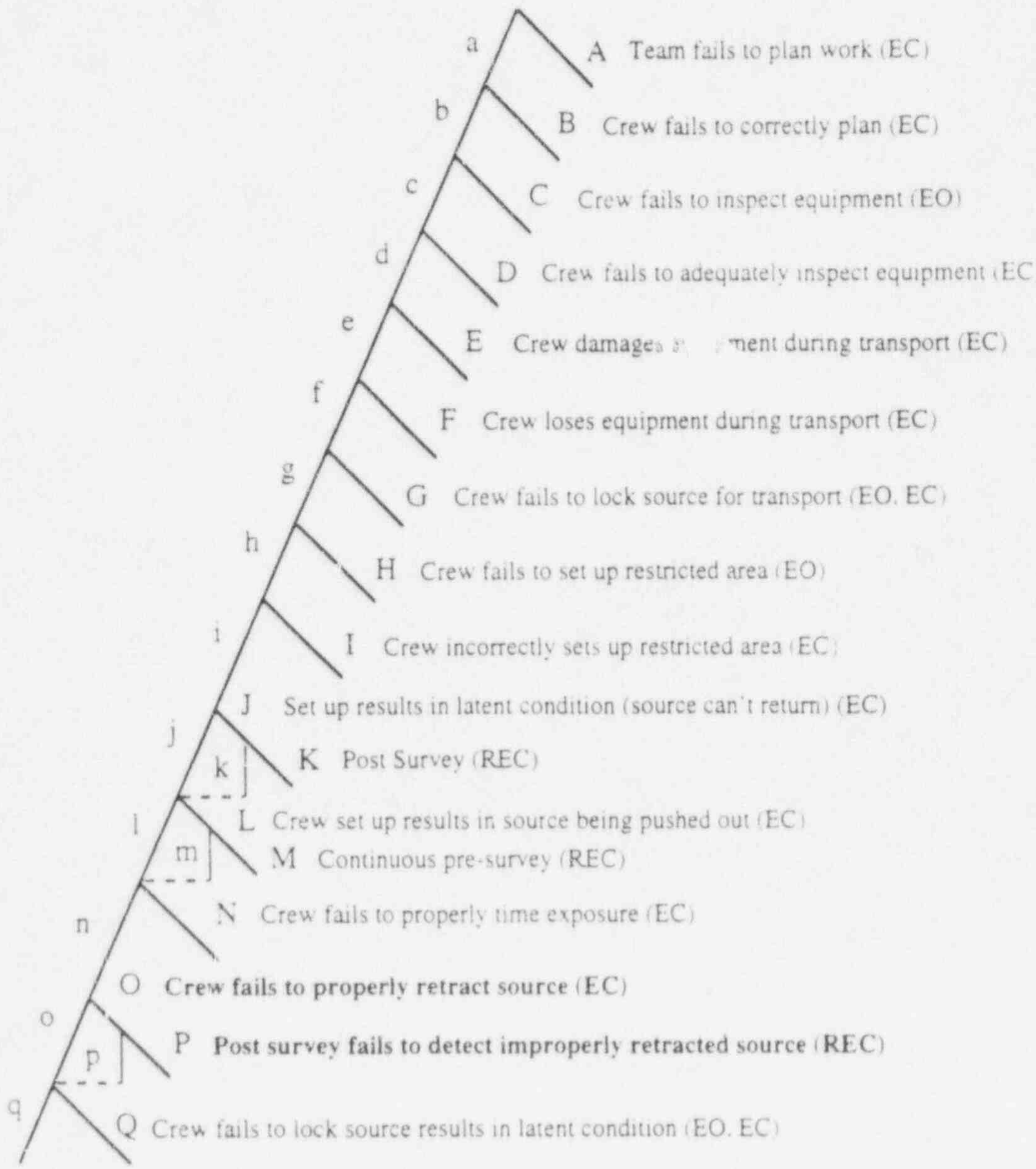
Appendix B
Section 5

5

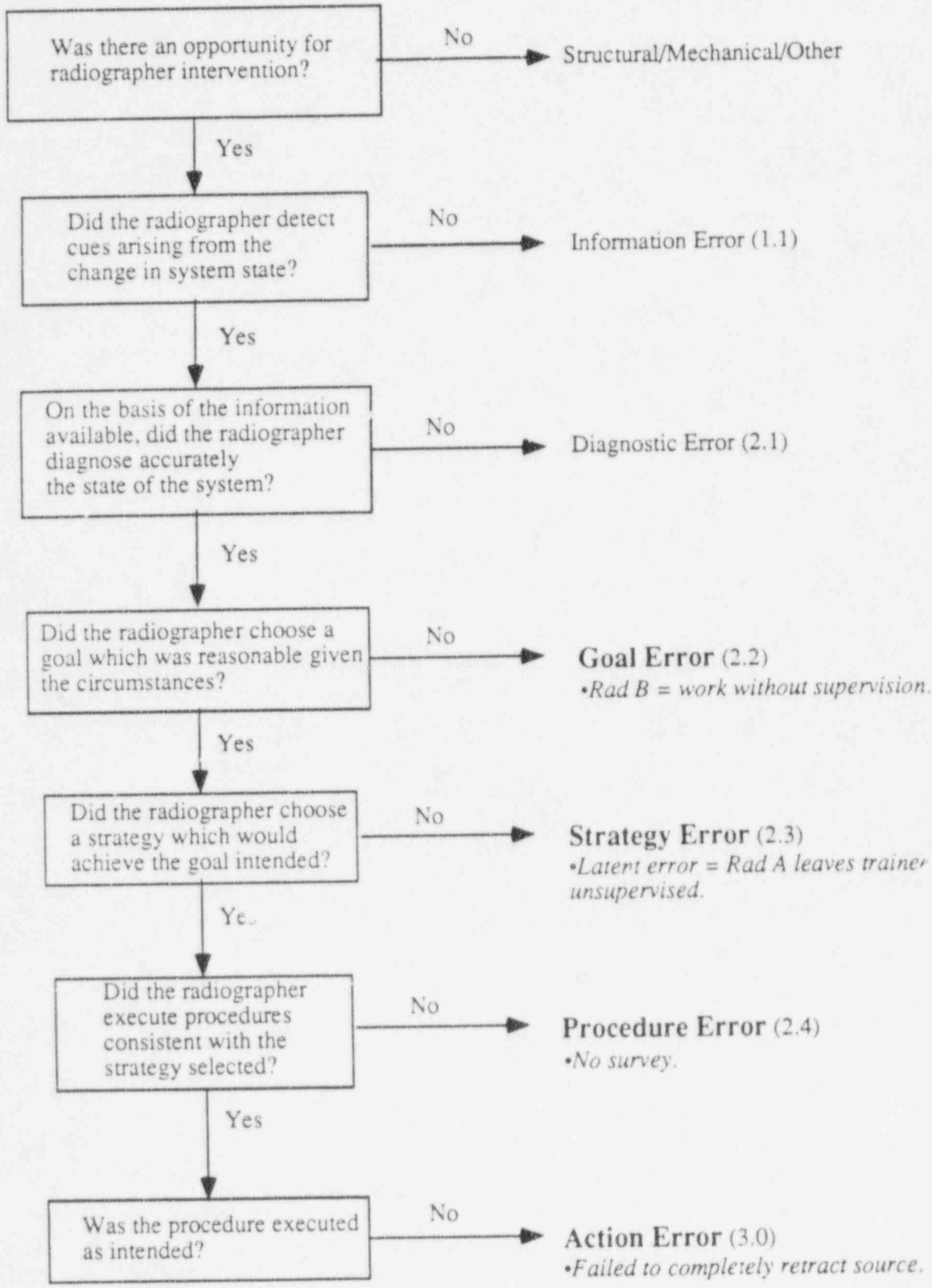
person	operation	equipment
A, B	radiographer/trainer (A) and trainee (B) set up at 8:30 a.m.	
A	took radiographs	
B	assisted in taking radiographs	
A	told B to watch camera	
A	went to remote site to develop film	
B	moved camera	
B	set new film	
B	performed radiograph	
B	thought he cranked back source	
A	returned and way survey meter at full scale	survey meter
A	turned crank out handle approximately 3/4 turn (to return source to shielded position)	
B	checked pocket dosimeter and found it offscale	dosimeter
A	shut down job and called office	

* did not use alarm ratemeter
* possible "hang-up" in guide tube
* trainee wanted to "speed up the job a little bit"

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Trainee • Wanted to "speed up" job	Strategy Error	Radiographer left trainee alone with camera	Trainee failed to retract source while working without supervision.
	Goal Error	Trainee performed radiography without supervision	
	Procedure	Failed to verify source retracted with survey	
		Failed to completely retract source	

OUTCOME

Trainee overexposed

• 21.36 REM whole body

CORRECTIVE ACTIONS

Equipment taken out of service.

Alarming ratemeters now required by licensee.

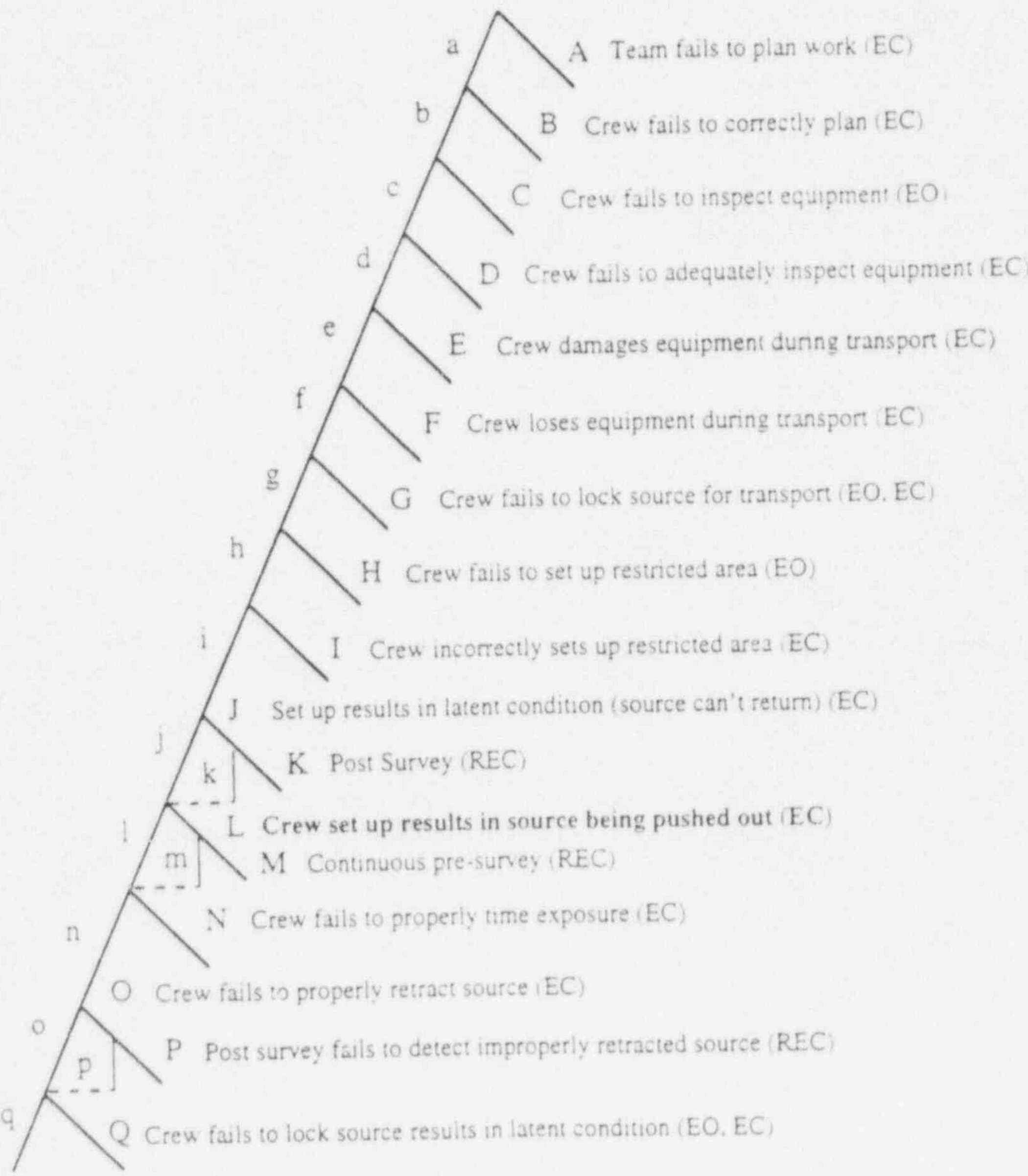
Trainee restricted from radiation work.

Licensee reduced number of radiographic personnel for better control of staff.

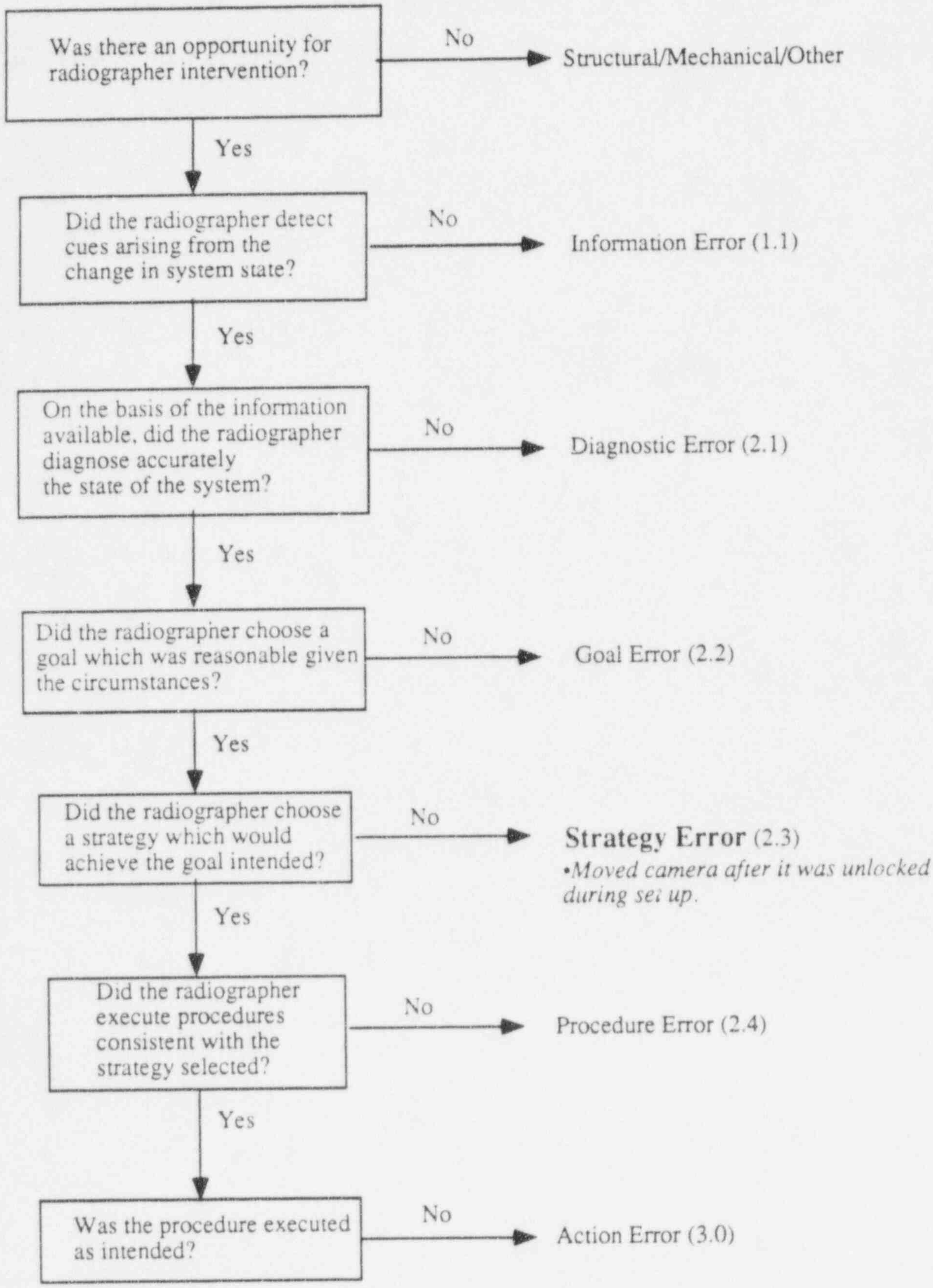
Appendix B
Section 6

Person	Operation	Equipment
A	crew took radiographic shot	
A	crew locked equipment	
A	~6 pm--moved to new site without disassembly (had worked 11 hrs so far that day)	camera
A	establish new restricted area	
A	positioned camera on scaffold (4 ft high)	
A	set up film on other side of pipe	
B	set up guide tube & collimator on one side of pipe	
A	climbed off scaffold	
A	unlocked camera	
A	adjusting collimator	
A	noted tight bend in guide tube	
A	placed left hand on camera and right hand on control cable	
A	turned camera (turned 15 to 20 degrees)	camera
B	climbed off scaffold (did not perform survey)	survey meter
A	noticed survey instrument off-scale on x1 setting	survey meter
A	turned setting to x10 (off-scale)	survey meter
A	performed battery check of survey meter (battery OK)	survey meter
A	picked up control cable handle and turned back 1/4 turn (survey reading returned to normal)	survey meter
A	surveyed camera (normal readings)	survey meter
A	notified site project leader of incident (both Rad A and Rad B pocket dosimeters off-scale)	dosimeters

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• 11 hours into shift	Strategy Error (circumvention) →	Failed to lock camera prior to adjusting for bend in guide tube	Radiographer turned unlocked camera during set up, moving source out of shielded position.

OUTCOME

Radiographer exposed

• 4.47 REM whole body

CORRECTIVE ACTIONS

(Unknown)

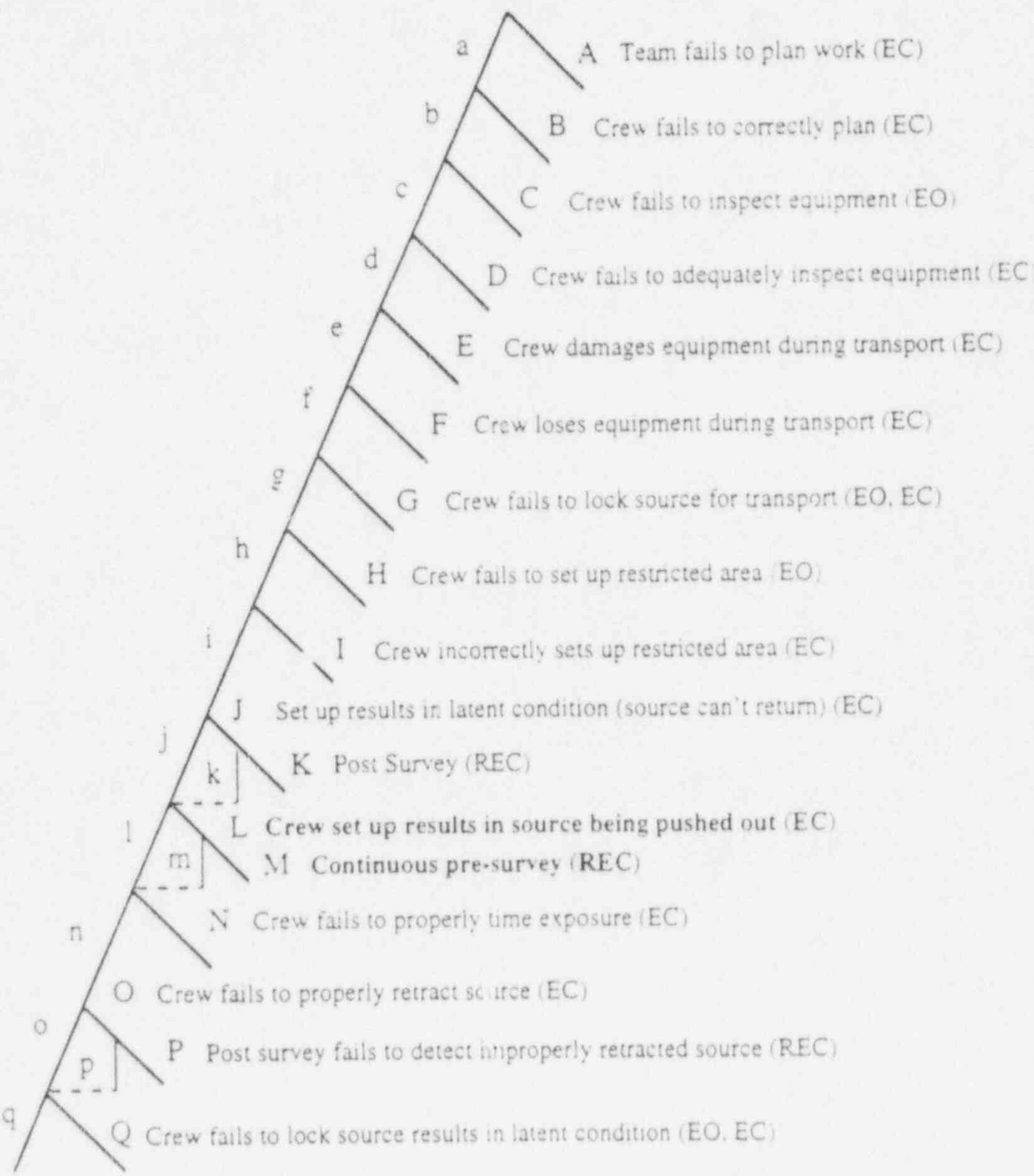
Appendix B
Section 7

7

person	operation	equipment
A	crew took radiograph with camera located 20 ft off ground (with drive cable hanging down with crank on ground)	exposure device
A	ascended to camera in manlift with survey meter	
B	replacing signs at restricted area border	
A	at height, moved manlift forward to camera	
A	surveyed guide tube & exposure device	
A	set meter on manlift floor	
A	grabbed control cable with right hand	
A	locked device with left hand	
A	reached in front and disconnected guide tube	
A	noticed source protruding several inches from front exit port source protruding from locked device	source, locked exposure device
A	dropped guide tube, descended to ground (Rad A dosimeter offscale, alarming ratemeter was turned off and not operable)	survey meter
A	tried to retract source but could not retract (lock plunger was depressed and in lock mode)	
A	discussed & planned what to do	
B	discussed & planned what to do	
B	ascended on manlift	
A	maintained tension on drive cable	
B	unlocked device	
A	retracted source	
B	surveyed	
B	relocked camera device	

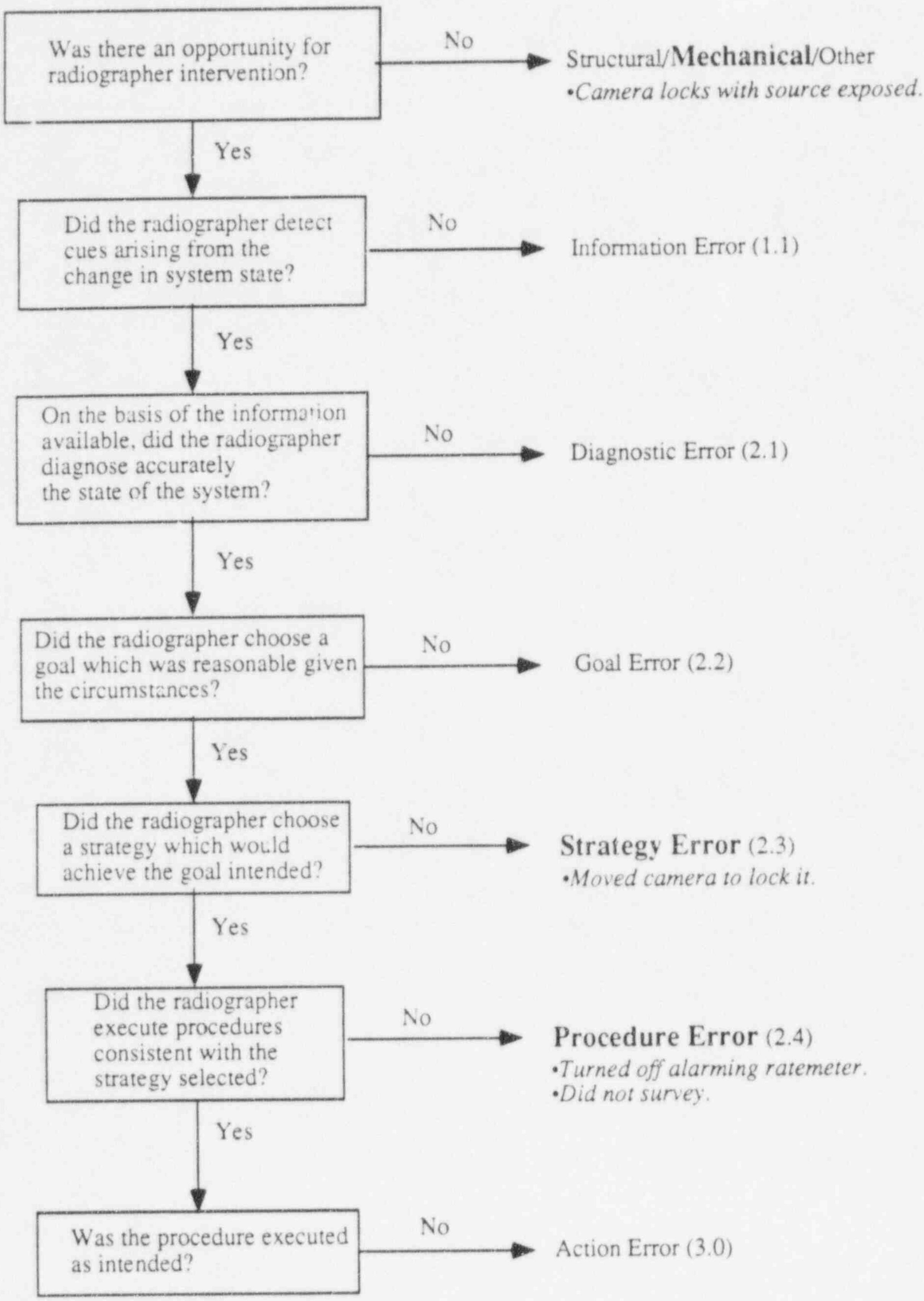
* did not know that a camera could be locked with source not in shielded position.

Event Tree for Generic Radiography



Appendix B
Section 8

Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982) 7



Error Influences & Effects

PSEs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Working on scaffolding; approached via manlift • Camera can lock with source exposed	Procedure	Turned off alarming ratemeter Did not survey after retracting source while locking	Radiographer moved camera while locking and did not know the source was exposed when disconnecting the guide tube.
• Turned off alarming ratemeter during paperwork to conserve battery	Strategy Error	Moved camera while attempting to lock	

OUTCOME

Radiographer overexposed

• 500 - 1000 REM hand

(• 0.25 REM whole body)

CORRECTIVE ACTIONS

Restricted radiographer from work with radioactive material.

Sent memo alerting to possible locking problems; need for proper surveys; turn on alarming ratemeters.

Additional training on, and inspection of alarming ratemeter use.

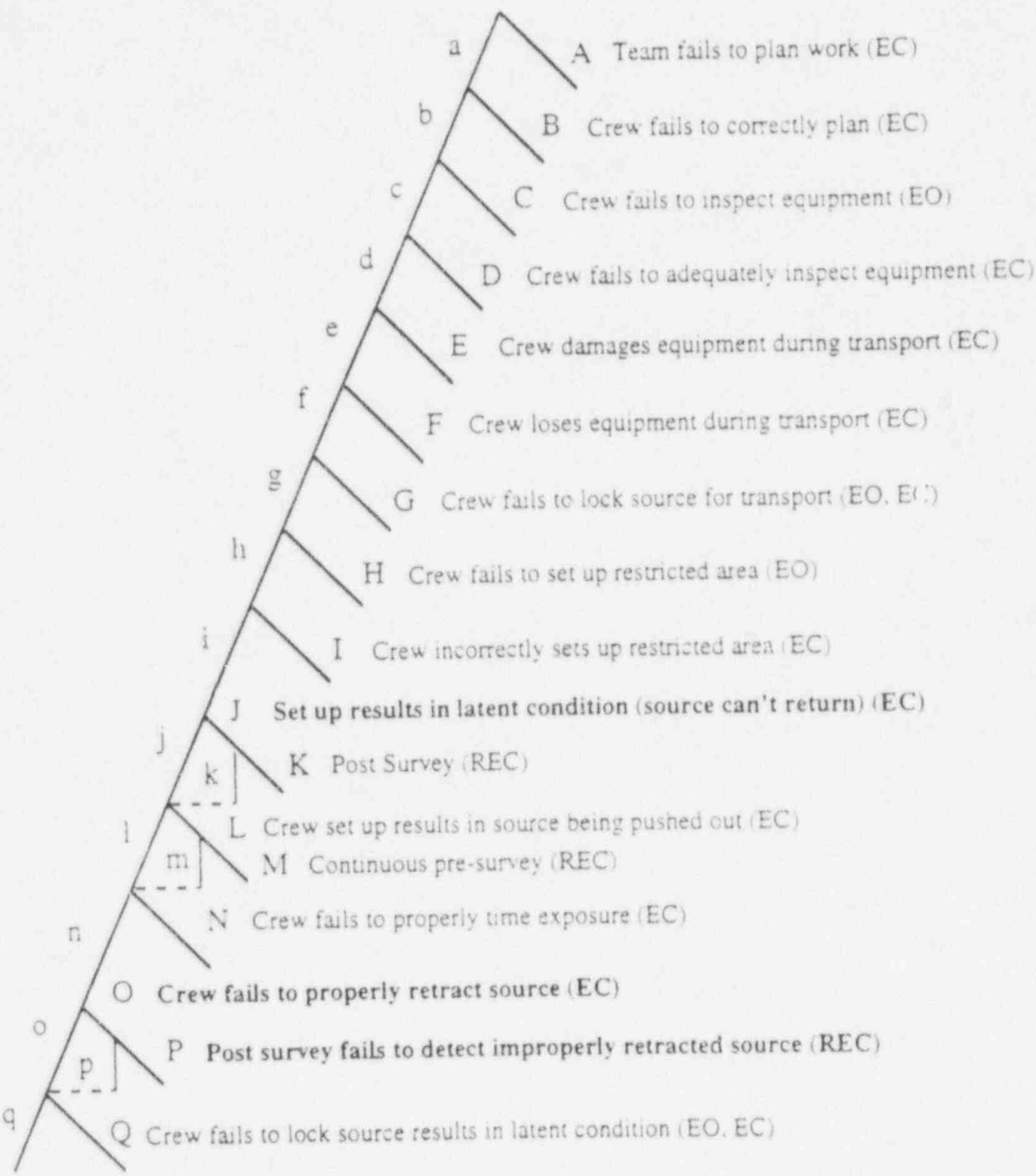
Civil penalty of $5000 imposed.

8

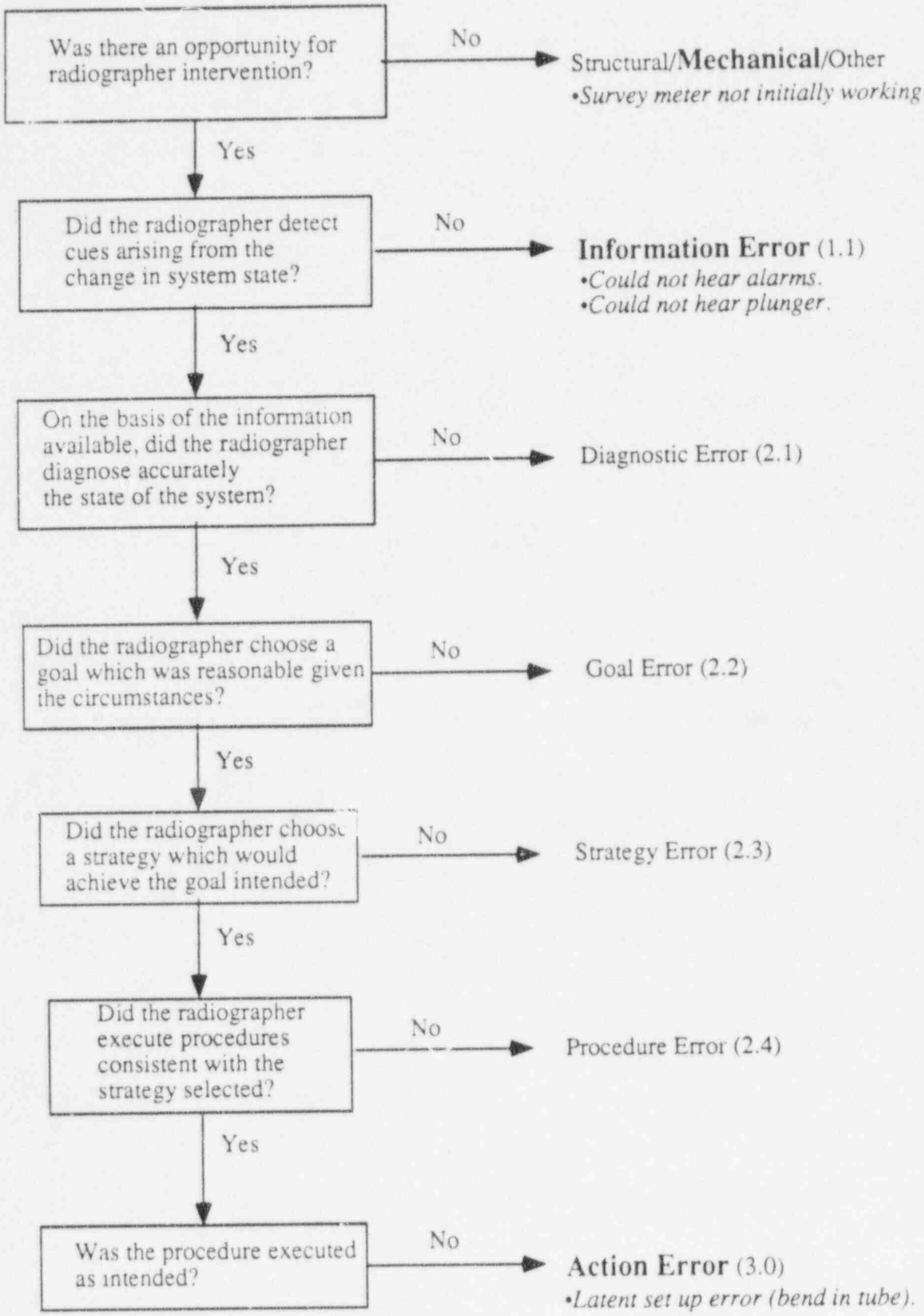
person	operation	equipment
A	radiographer (A) took 8 minute exposure at about 1:30 a.m.	
A	cranked in source (could not hear plunger on lock of camera because of high noise - had on double ear protection, sharp bend in guide tube from setup may have prevented source from fully retracting)	source, ear protecti-
A	approached camera with survey meter on x10 scale	
A	saw survey meter reading was 0	survey meter
A	told radiographer (B) to leave area	
A, B	left camera area (could not hear alarm meters)	
A	checked survey meter (batteries not making contact)	survey meter
A	tapped meter and it began functioning	
A	cranked source out and back in	
A	approached camera with meter	
A	surveyed	
A	locked camera	
A	notified RSO	

* alarm meters - wearing, in working order, but could not hear due to noise

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• High noise area • Wearing ear protection (which prevented hearing alarming rateme[illegible]	Mechanical →	Approached camera with survey meter at zero (but then retreated)	Radiographer failed to retract source, given failed survey meters.
	Information →	Relied upon audible cues when in high noise/ear protection area	
	Action error →	Set up resulted in sharp bend in guide tube	

OUTCOME

Radiographer possible overexposure (if hand touched guide tube)

- 146 REM extremity (calculated

CORRECTIVE ACTIONS

Removed survey meter from service.

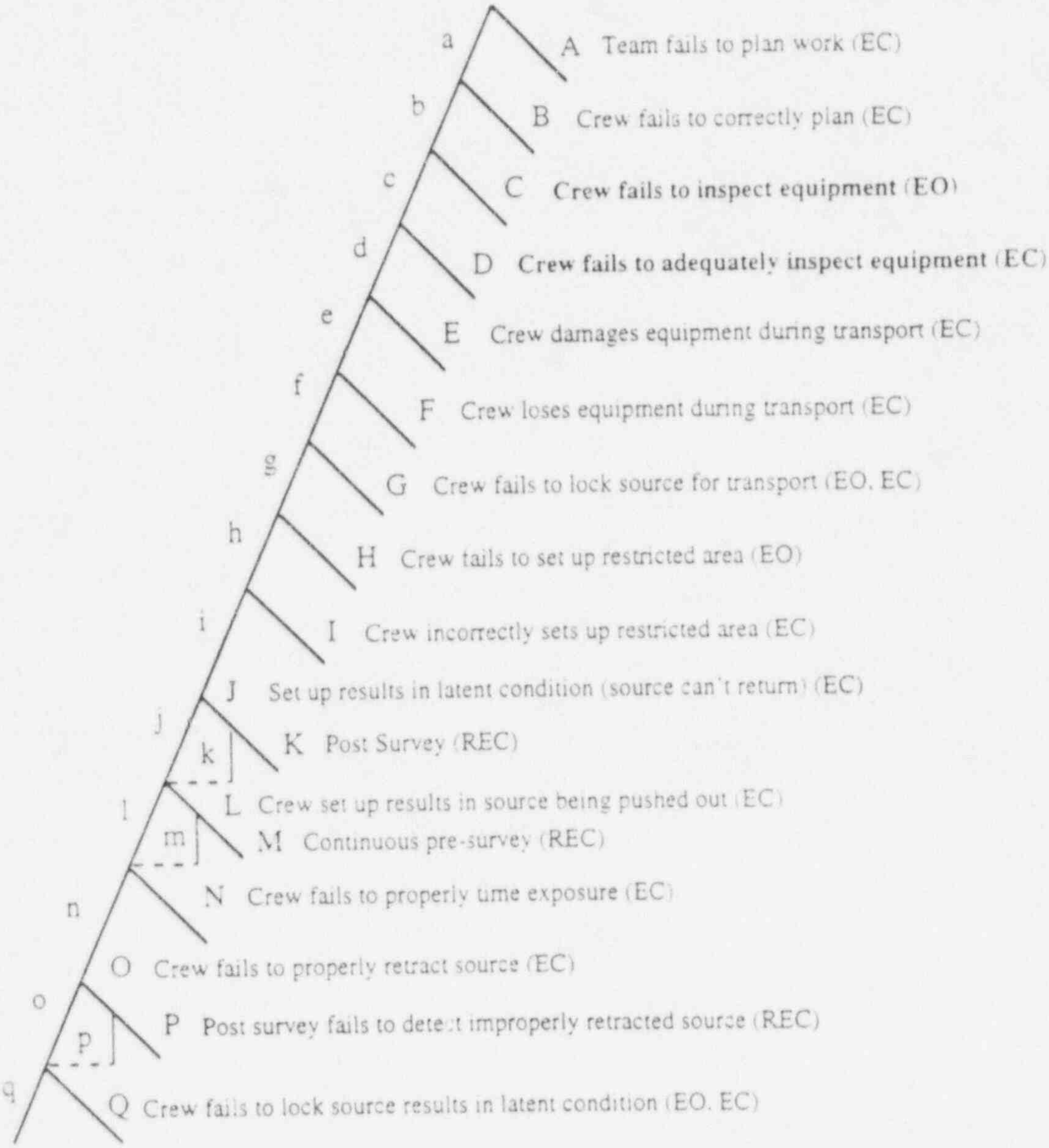
Maintenance inspection on all related equipment.

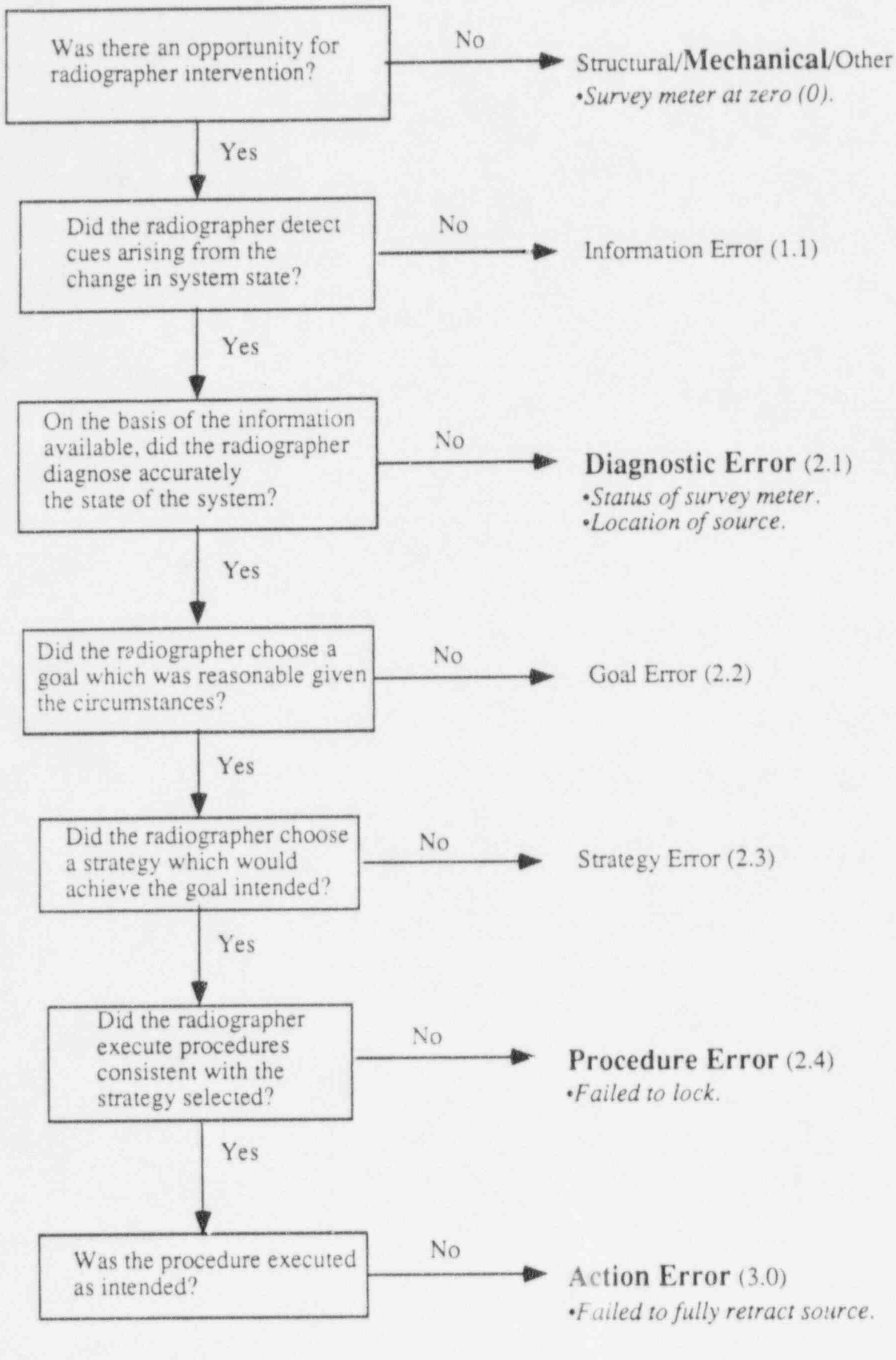
Appendix B
Section 9

9

Person	operation	equipment
A/B	two radiographers (A and B) zeroed dosimeters at beginning of work	
A.B	completed necessary paperwork	
A/B	began to make exposures on first of ten welds	
A	proceeded to darkroom to develop film after completion of ten welds	
B	continued to make exposures on next set of welds	
B	set up for next exposure	
B	unlocked exposure device	
B	walked back with survey meter and crank outs	
B	cranked out approx 1/4 revolution and source hung up in guide tube	crank control, source, guide tube
B	realized there was a problem when couldn't get source to go any further	source
B	tried to retract source back into exposure device	source, exposure device
B	thought he had retracted source back into exposure device	source, exposure device
B	surveyed exposure device	survey meter, exposure device
B	observed survey meter reading of 0	survey meter
B	checked guide tube, thinking it might be kinked	
B	returned to crank out	
B	couldn't get source to move from original position	source
B	approached exposure device with survey meter	survey meter, exposure device
B	removed guide tube from exposure device	guide tube, exposure device
B	saw source just outside of exposure device	source, exposure device
	(at no time did ratemeter alarm sound)	ratemeter alarm
B	returned to crank out	
B	retracted source into exposure device	
B	informed A, who was still in darkroom	
A	picked up survey meter	survey meter
A	noticed meter not working at all	survey meter
A	tapped survey meter and it began working properly	survey meter
B	(never performed lock out survey)	survey meter
B	(never locked exposure device)	exposure device
A/B	called RSO	

Event Tree for Generic Radiography




Was there an opportunity for radiographer intervention?
No
Structural/Mechanical/Other
•Survey meter at zero (0).
Yes
Did the radiographer detect cues arising from the change in system state?
No
Information Error (1.1)
Yes
On the basis of the information available, did the radiographer diagnose accurately the state of the system?
No
Diagnostic Error (2.1)
•Status of survey meter.
•Location of source.
Yes
Did the radiographer choose a goal which was reasonable given the circumstances?
No
Goal Error (2.2)
Yes
Did the radiographer choose a strategy which would achieve the goal intended?
No
Strategy Error (2.3)
Yes
Did the radiographer execute procedures consistent with the strategy selected?
No
Procedure Error (2.4)
•Failed to lock.
Yes
Was the procedure executed as intended?
No
Action Error (3.0)
•Failed to fully retract source.

Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
(Unknown)	Mechanical	Approached camera with survey meter at zero	Radiographer failed to recognize faulty meter when approaching camera and disconnecting guide tube (with source exposed).
	Diagnostic	Continued working after noting zero reading on survey meter	
	Procedure	Failed to lock camera	
	Action error	Failed to fully retract source	

OUTCOME

Radiographer exposed

- 15 REM hand
- 0.36 REM whole body

CORRECTIVE ACTIONS

Required exposed worker to attend and complete 40 hour radiation safety training course on his own time and at his own expense.

Appendix B
Section 10

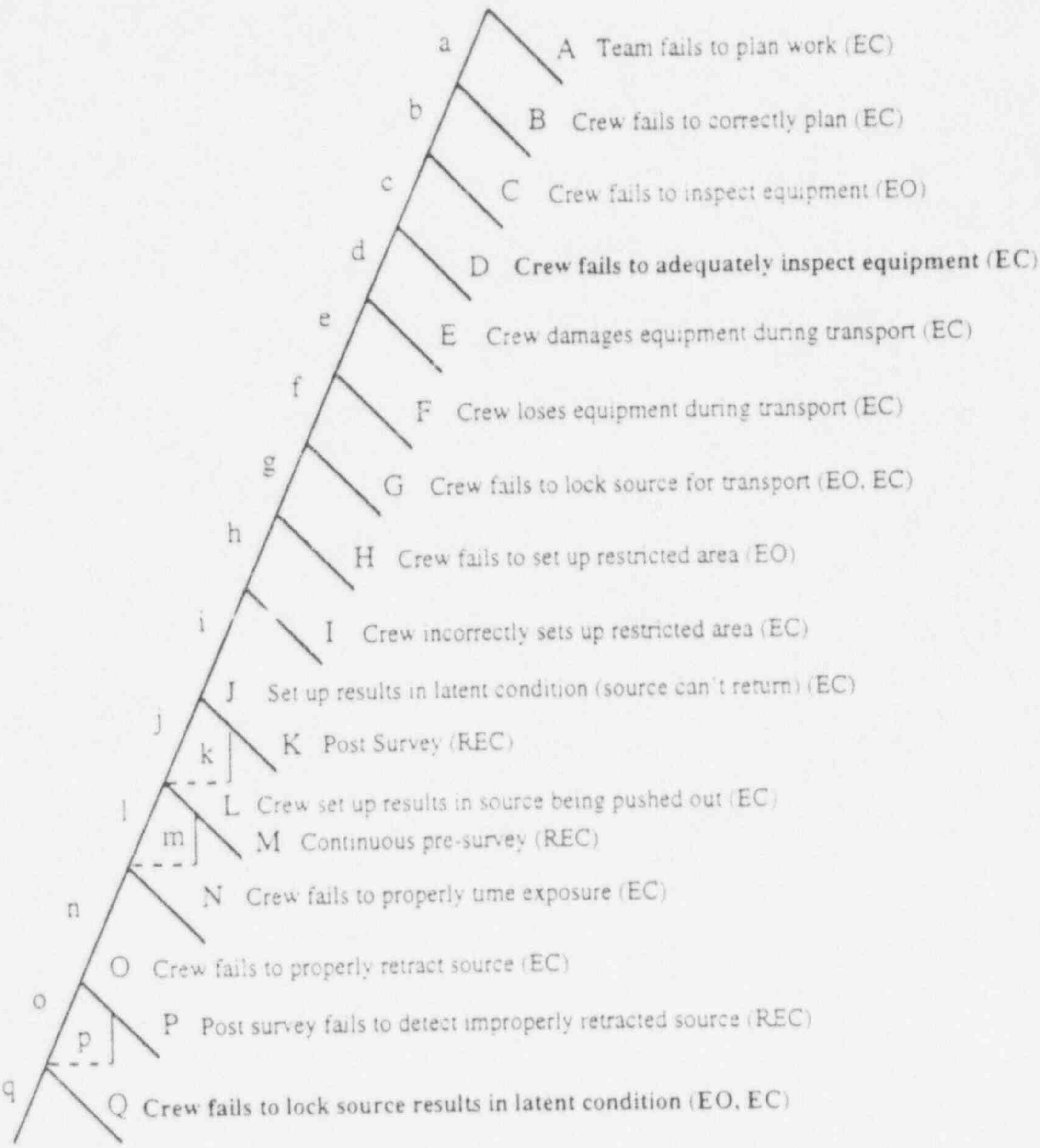
10

Person	operation	equipment
A	cleared the area to be roped off	
	calculated safe perimeter t be blocked off	
A	positioned helpers, outside restricted area, for additional security	
A	set up safe perimeter (unrestricted area)	
A	set up safe area to control cable crank	
A	checked out survey meter	
A	secured exposure device	
A	positioned source guide tube and jig	
A	laid out source tube to spot where camera would be positioned	
A	placed ply board under camera end of guide tube connection	
A	placed camera on ply board to allow easy connection of guide tube	
A	crank control unit extended out and around in a "u" shape	
A	removed exposure device storage plug	
A	connected source guide tube to the exposure device	
A	placed storage plug in storage tube on front of the camera	
A	followed figures 5.2-5.6 in the Tech/Ops Operation Manual to connect control unit to exposure device	
A	surveyed exposure device	
A	unlocked exposure device (selector ring in "operate" mode)	
A	positioned control unit in safe location	
A	set odometer knob at 000	
A	checked restricted area	
A	checked that helpers in unrestricted area were alert	
A	cranked out source to tip of guide tube stop	
A	put brake in "on" position	
A	surveyed unrestricted outer perimeter	
A	returned to crank control	
A	set brake to "off"	
A	retracted source to safe position in camera	
A	set brake to "on"	
A	entered R.T. area	
A	surveyed guide tube	
A	verified source safely secured in camera	

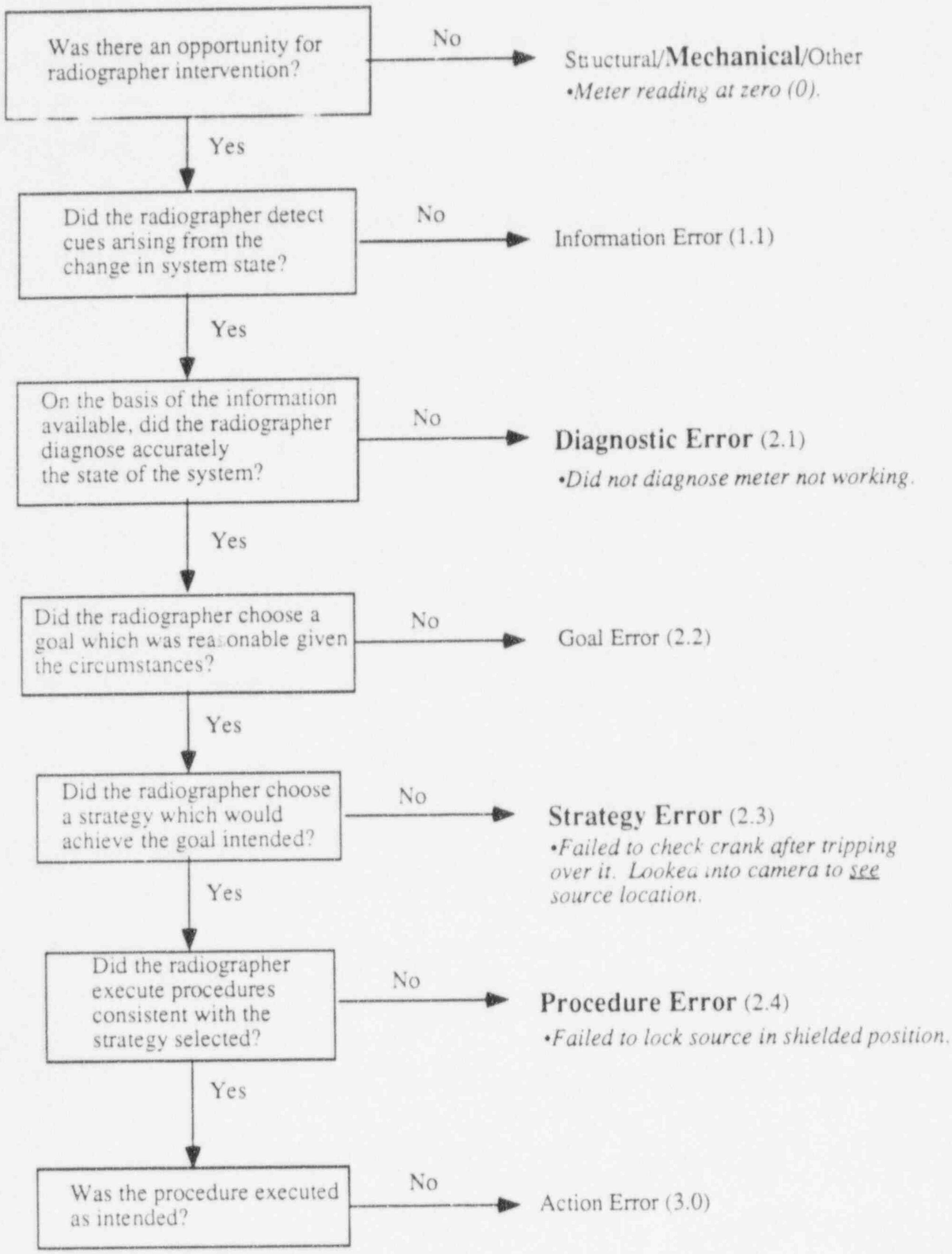
A	placed survey meter down near exposure device	
A	got unexposed film from safe shielded area	
A	placed film and I.D. on area to be x-rayed	
A	rechecked S.F.D. for the proper distance	
A	visually checked restricted and unrestricted area and helpers	
A	released brake for crank control	
A	cranked out source to full exposure position at end of guide tube stop	
A	(did not use brake during exposures because of short time)	brake
A	retracted source to safe shielded position	
A	followed above procedures for nine exposures	
A	cranked source back to safe position after tenth exposure	
A	noticed odometer readings all in 000 position	
A	surveyed (no radiation readings)	
A	became anxious to complete the job and wrap up everything	
A	rushed towards exposure device	
A	kicked control crank while stepped over crank control, which evidently moved the crank and moved the source out towards the tip of the camera	control crank, source
A	surveyed from source guide tube stop end back to the exposure device	
A	observed survey readings at 0	survey meter
A	set survey meter down	
A	removed jig	
A	removed x-rayed film and I.D.	
A	put film on skip	
A	put lead numbers in container on ply board where exposure device was	
A	removed source guide tube from jig	
A	put guide tube and jig on skip	
A	detached guide tube connection at front of exposure device	guide tube, exposure device
A	removed storage plug from holder	
A	attempted to secure storage plug, but couldn't (tip of plug wouldn't go in further than entrance at front of exposure device)	storage plug, exposure device
A	realized that source was not fully retracted	source
A	visually checked front opening	exposure device
A	noticed something that looked like the tip of a small capsule	source
A	turned knob of survey meter to "battery check"	survey meter
A	observed needle to jump up, then back down to 0	survey meter
A	removed bottom of survey meter casing to get to the battery	

A	put pressure on batteries while rotating them	survey meter
A	read survey meter off scale	survey meter
A	read pocket dosimeter off scale	pocket dosimeter
A	put both meters down	
A	ran back to crank control	
A	retracted source to fully shielded position (moved just a little)	crank control, source
A	returned to camera	
A	secured storage plug into exposure device	
A	turned rotating selector ring into lock position	
A	surveyed camera	
A	noticed survey meter fluctuating (as if having bad contact)	survey meter
A	removed bracket holding batteries in place	survey meter, battery bracket
A	bent bracket to fit snugly against batteries	survey meter, battery bracket
A	replaced bracket support back	
A	noticed that problem was solved	
A	survey device again (no problems)	
A	rotated selector ring from lock to connect (to disengage control unit connector)	
A	followed procedures in figures 5.6-5.2 in the Tech/Ops Operation Manual to properly disengage the control unit from the exposure device	
A	locked and secured storage cover	
A	removed key	
A	surveyed camera again	
A	temporarily stored camera in secured cab of the truck	
A	secured crank control, source guide tube, film, etc. in proper place	
A, others	removed signs and barriers	
A	developed last of the x-rays	
A	found first nine x-rays to be OK, tenth was black	film
A	reported incident to state health department	
A	reported incident to USNRC	
A	called company that processes film badges to have them get results as soon as possible	
A	reviewed complete incident the next day	
A	mailed film badge to processor	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Last of 10 shots • "Anxious" to complete job	Procedure →	Failed to lock source in shielded position	Radiographer disconnected guide tube and attempted to insert storage plug with source exposed.
	Diagnostic →	Continued working after noting zero reading on survey meter in front of camera	
	Strategy Error →	Failed to check crank and odometer after tripping over it	
	Strategy Error →	Looked into front port of camera to observe source	

OUTCOME

Radiographer Exposure

- 6.1 REM whole body
- 118 REM hand
- 2 REM lens of eye

CORRECTIVE ACTIONS

None listed; radiographer was president and general manager of the licensee company.

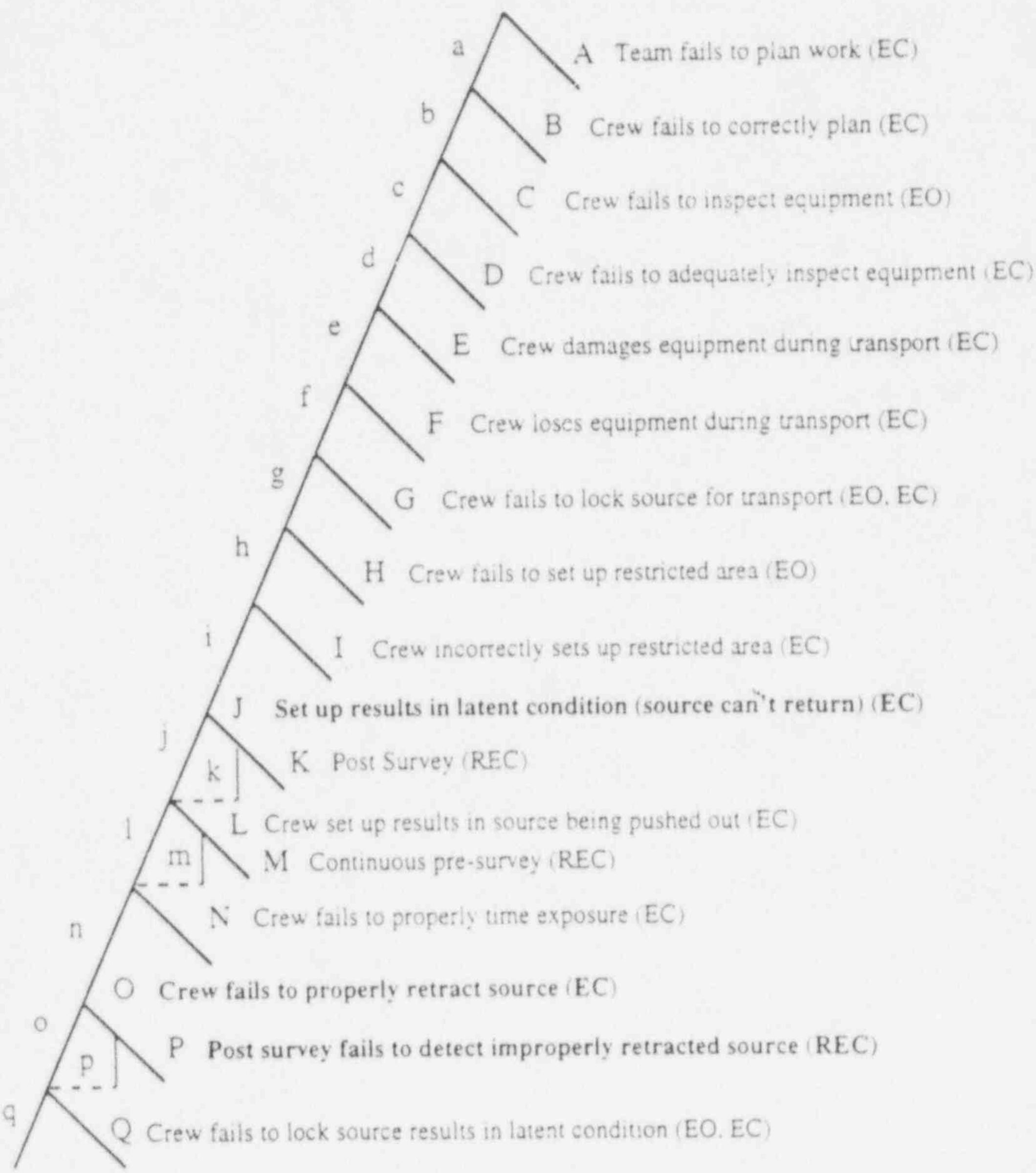
Thorough evaluation of incident in report, with extensive section on steps which should have been taken to avoid the situation.

Appendix B
Section 11

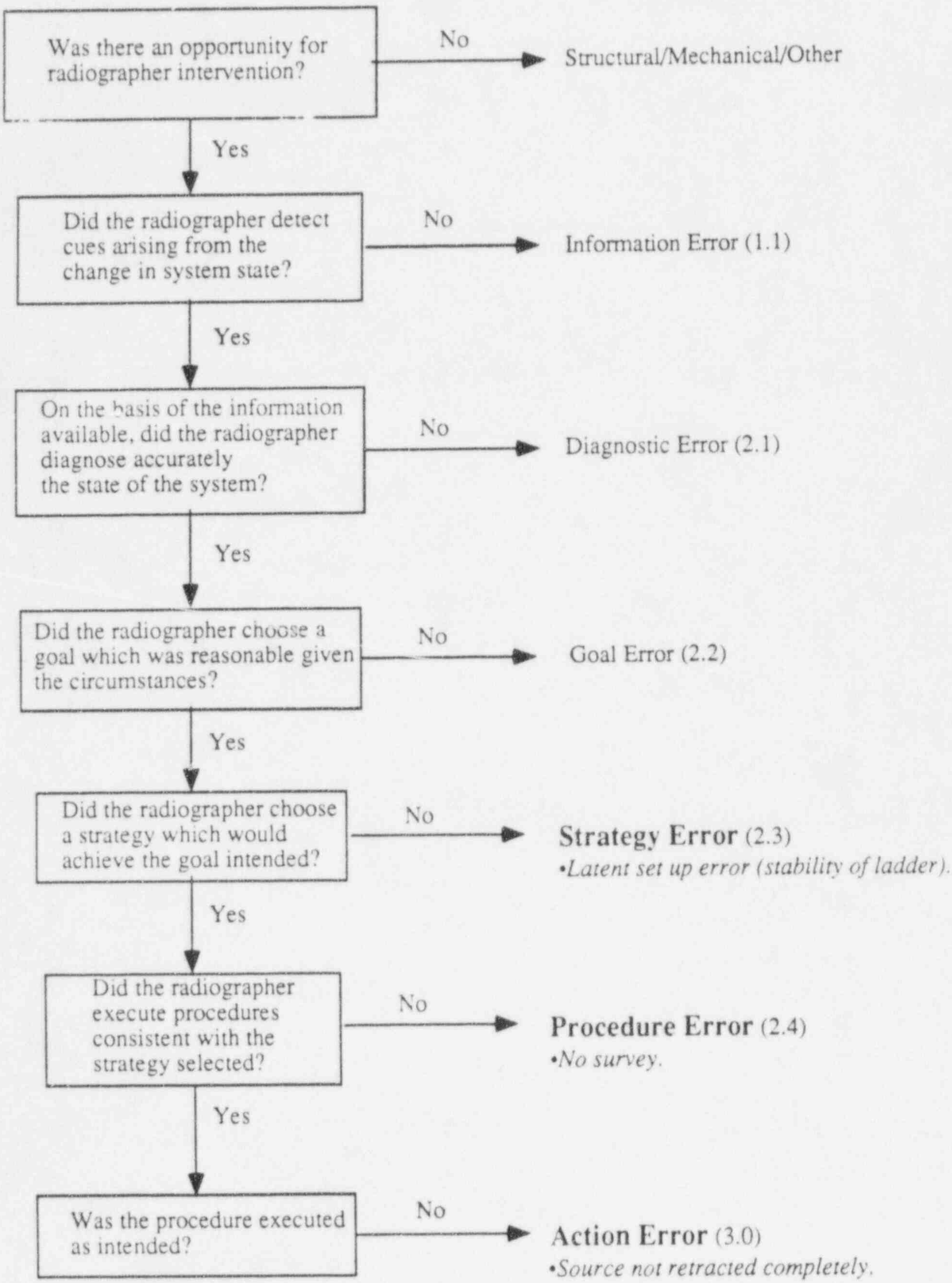
11

Person	operation	equipment
A	radiographer (A) completed exposure on weld joint	
A	approached camera on ladder step approximately 8' off ground	camera, ladder
A	held crank control mechanism in right hand	crank control
A	attempted to push lock plunger down to secured position	lock plunger
A	made 2nd attempt to push plunger down and camera started to fall off ladder	lock plunger, camera
A	grabbed guide tube at the port window to balance the camera	guide tube, camera
A	called B to help	
B	noticed survey meter offscale	survey meter
B	informed A that survey meter was offscale	
A	backed away approximately 10' to straighten control cable	
A	turned crank approximately 1/3 turn	
B	read survey meter at normal	
A	confirmed that source was in safe shielded position	
A/B	checked pocket dosimeters (A = 60 mrem, B = 5 mrem)	
A	notified RSO of incident	
A	reported results of dosimeter reading to RSO (C)	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
(Unknown)	Procedure →	Failed to survey when attempting to lock camera	Radiographer grabbed guide tube to steady falling camera (with source exposed).
	Strategy Error →	Camera placed in unstable position (on stepladder)	
	Action →	Failed to completely retract source	

OUTCOME

Radiographer Exposure

- 111.4 REM hand

CORRECTIVE ACTIONS

Written warning to radiographer of termination on next violation.

Safety meeting; brainstorming session to improve program; incident reports to be used for future classroom training.

Appointed Radiation Safety Monitor.

Purchase new gamma equipment with disconnect safety features.

Appendix B
Section 12

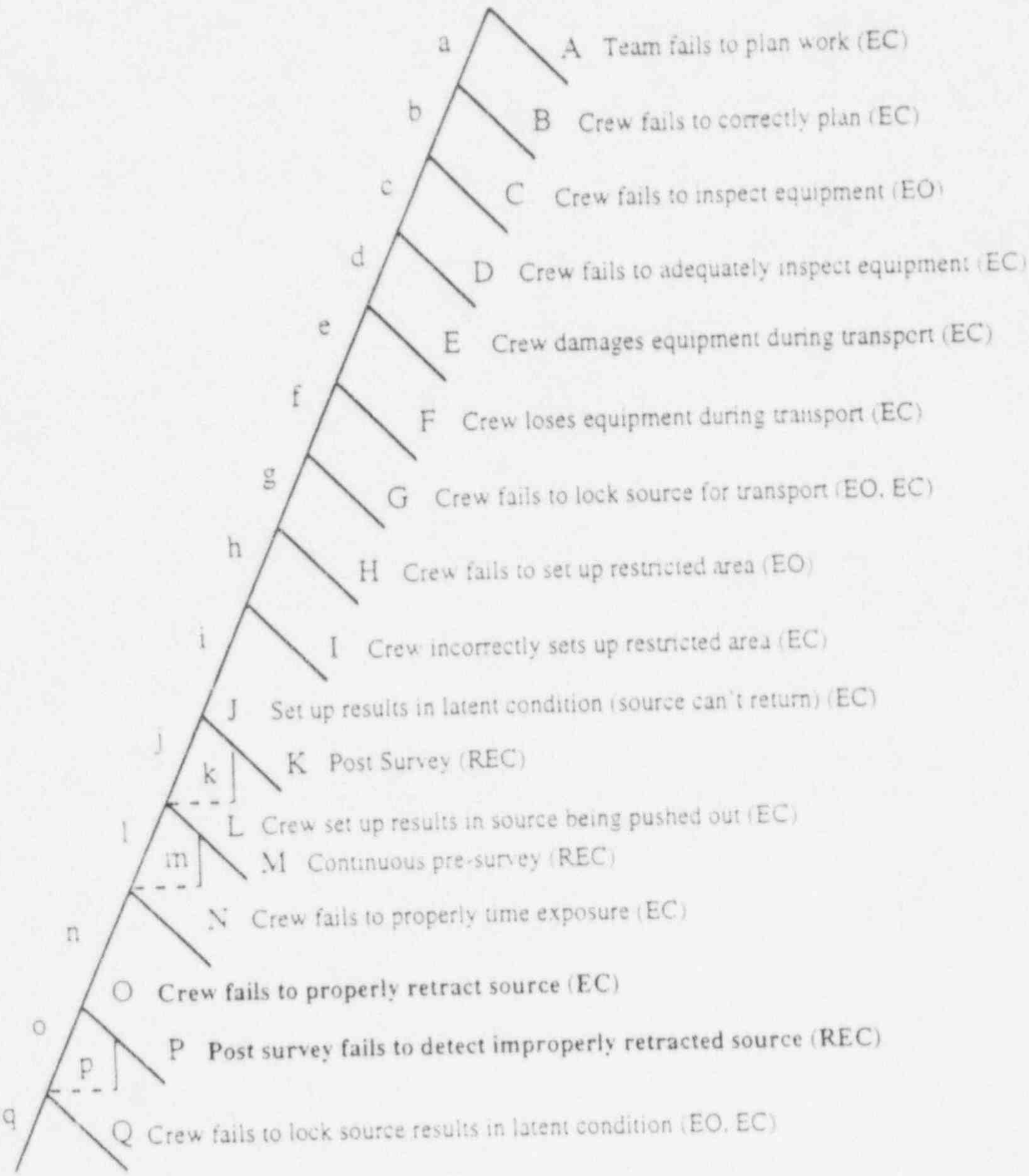
12

person	operation	equipment
A	assistant (A) failed to test pocket dosimeter for proper operation prior to the shift	pocket dosimeter
B	radiographer (B) left assistant working alone	
A	completed some x-rays	
A	failed to survey guide tube or circumference of exposure device	
A	failed to secure/lock sealed source assembly in the shielded position	source
A	picked up exposure device	
A	carried exposure device to location of next weld	
A	set device down	
A	went to truck, at previous site, to get film and survey meter that had been left behind	
A	returned to new weld site	
A	noticed survey meter was "pegged" off scale as approached exposure device	survey meter
A	backed away from device	
A	read pocket dosimeter (discharged beyond range), which had not sounded or alarmed at any time during the incident (may not have been turned on, hadn't been calibrated for over a year)	pocket dosimeter
A	returned to truck	
A	requested assistance of radiographer (B)	
B	proceeded to site where exposure device was located	
B	picked up control mechanism	
B	returned source to shielded position (required less than one full rotation of the crank mechanism)	
B	approached device with survey meter	
B	surveyed full length of guide tube and entire circumference of exposure device	
B	read indication of sealed source in shielded position	
B	secured/locked sealed source assembly in shielded position	
A/B	stopped work for the day	
A/B	left job site to notify RSO of incident	
A/B	wrote partially false statements to cover up the fact that the radiographer was not supervising assistant	

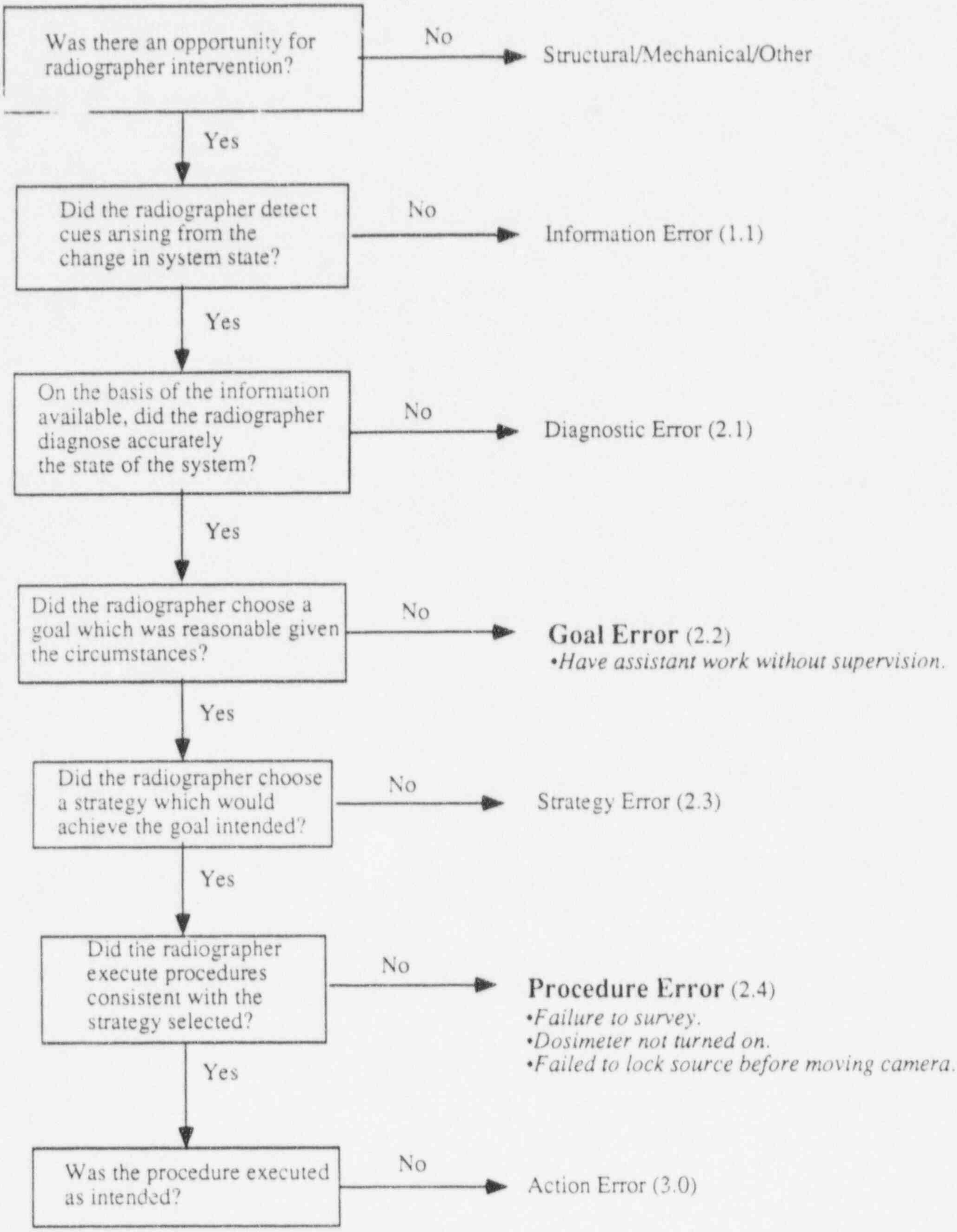
- It is not known for sure if this resulted in an overexposure
- There was a lot of contradictory information, and reports were falsified to protect the individuals involved.
- assistant informed RSO that she had falsified information on the report but had verbally provided him the actual details of the incident (later contradicted in another report)
- assistant stated that RSO performed a calculation on her exposure and informed her that she had not received an overexposure (RSO stated that he had performed a calculation but could not remember what it was and could not locate any documentation of it.)
- RSO gave the assistant another TLD and told her that she could go back to work as her husband's assistant (he was a radiographer also)

RSO stated that he sent the assistant's badge in for processing, but the badge vendor stated there was no record of receiving it

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Limited training • Limited experience	Procedure	Failed to turn on dosimeter Radiographer left assistant to work alone	Multiple unsafe actions led to probable exposure of assistant.
	Goal Error	Radiographer left assistant to work alone Assistant proceeded to work without supervision	
	Procedure	Moved camera without carrying survey meter Failed to survey properly	

OUTCOME

Assistant exposure

- Possible 6 REM whole body
- Film badge was lost

CORRECTIVE ACTIONS

Radiographer reminded to work according to NRC regulations.

Radiographer review of 10 CFR Part 34.

New assistant RSO appointed.

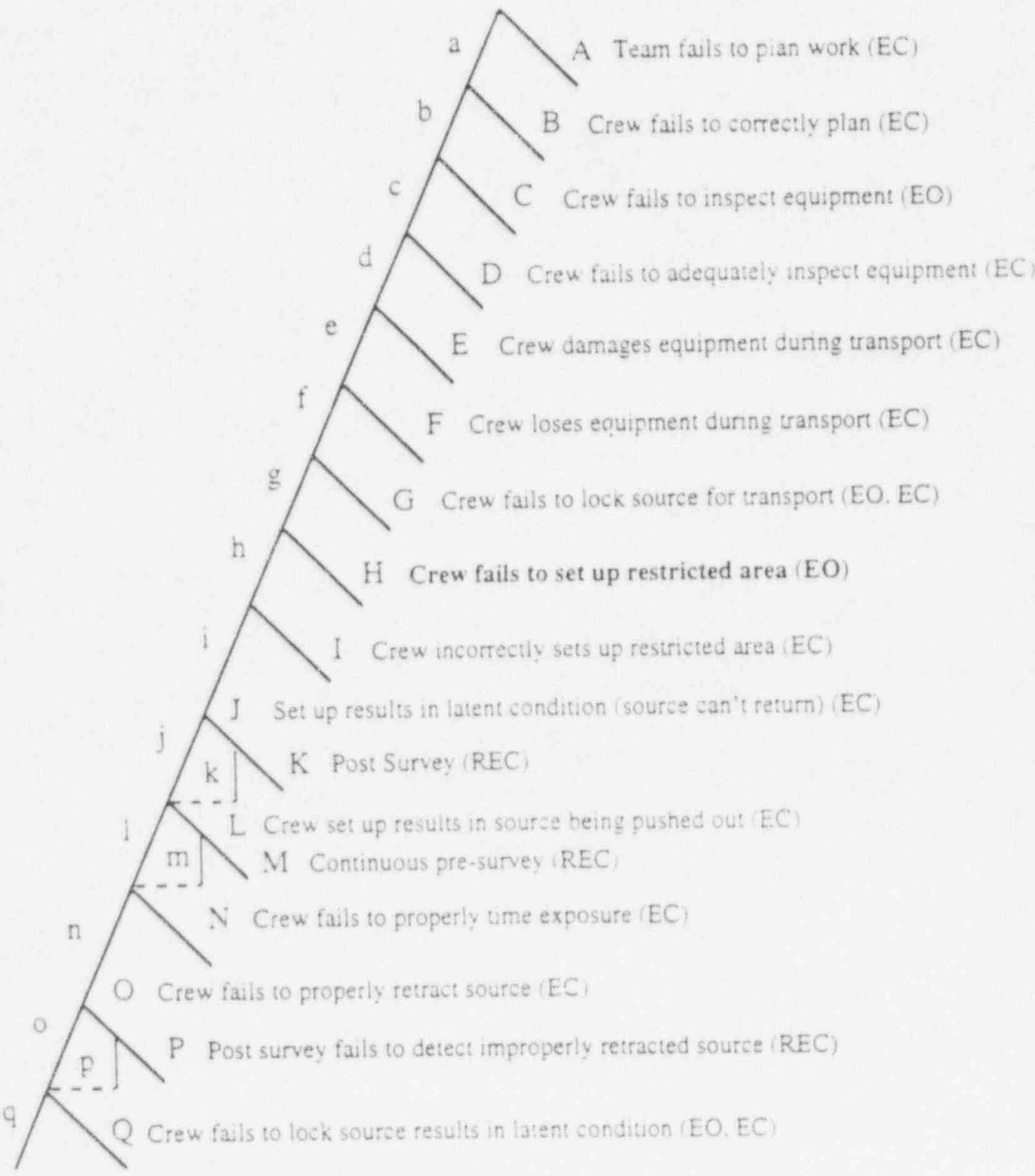
New calibration log initiated.

Appendix B
Section 13

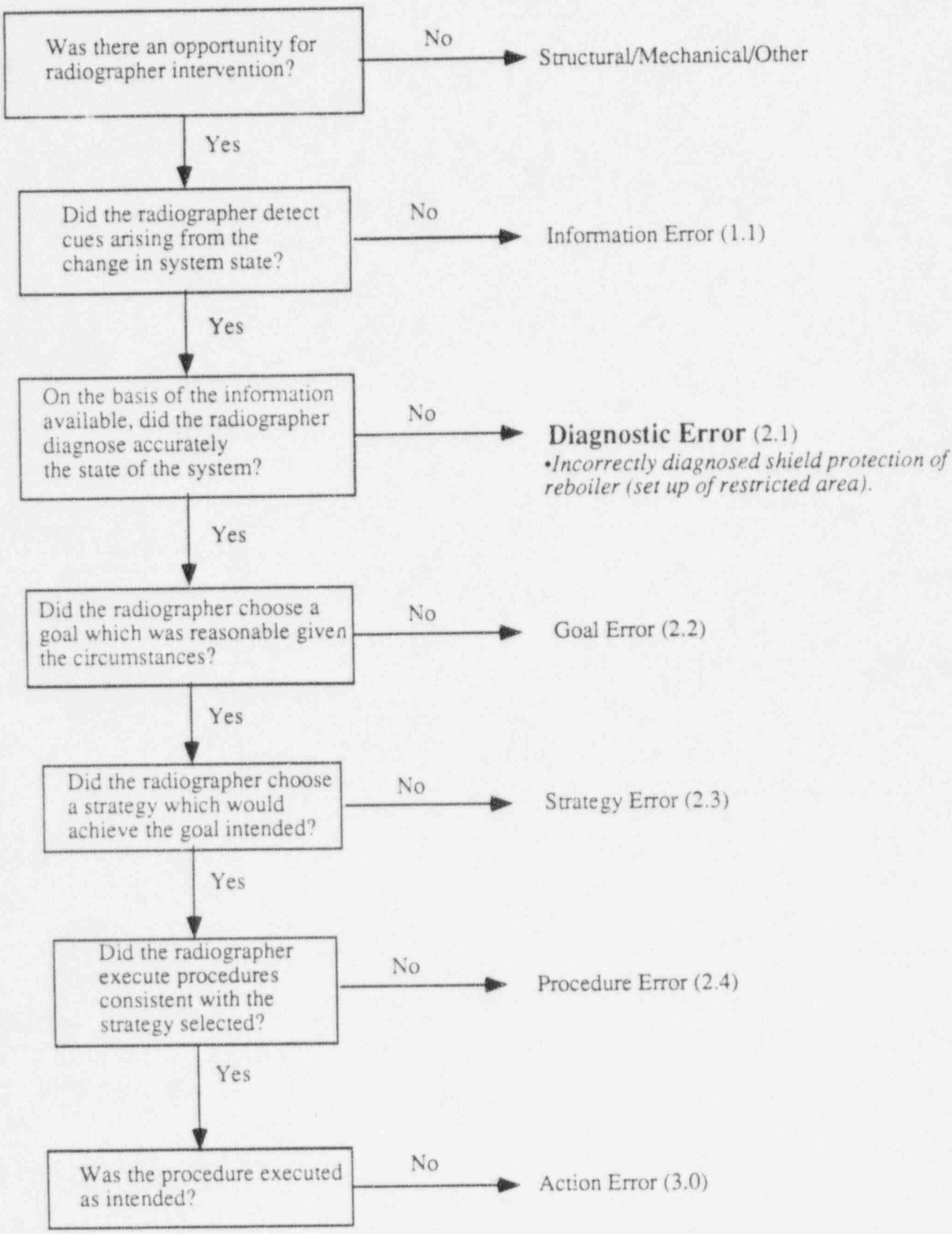
13

person	operation	equipment
?	two survey meters calibrated 1 week before incident	
3	radiographer trainer (B) wore film badge and pencil dosimeter	
C	radiographer trainee (C) wore film badge and pencil dosimeter	
C	assumed that re-boiler was lined with fire wall bricks and boiler tubes, did not actually look inside to see who was in it	
B	assumed that the inside of the reboiler should be an unrestricted area	
A	worker (A) working inside reboiler in area closest to source, separated by 3/16" thick steel reboiler shell, >8' from source during radiography exposures	
?	ropes and signs posted at the restricted area perimeter	
B/C	radiographers performed three exposures	
B	told by witness (E) (during or after last exposure) that worker was inside reboiler during exposure	
E	told trainer not to crank out because someone was working inside boiler, said trainer told him reboiler was lined with refractory, and proceeded to crank out	

Evert Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
(Unknown)	Diagnostic Error →	Incorrectly set up restricted area (Assumed no one in reboiler) (Assumed reboiler lined with firewall bricks and boiler tubes)	Non-radiation worker in reboiler exposed during x-ray.

OUTCOME

Non-Rad worker exposure

• 0.0184 REM whole body (calculated)

CORRECTIVE ACTIONS

Radiographer counselled; told to maintain more diligent attitude regarding radiation safety responsibilities.

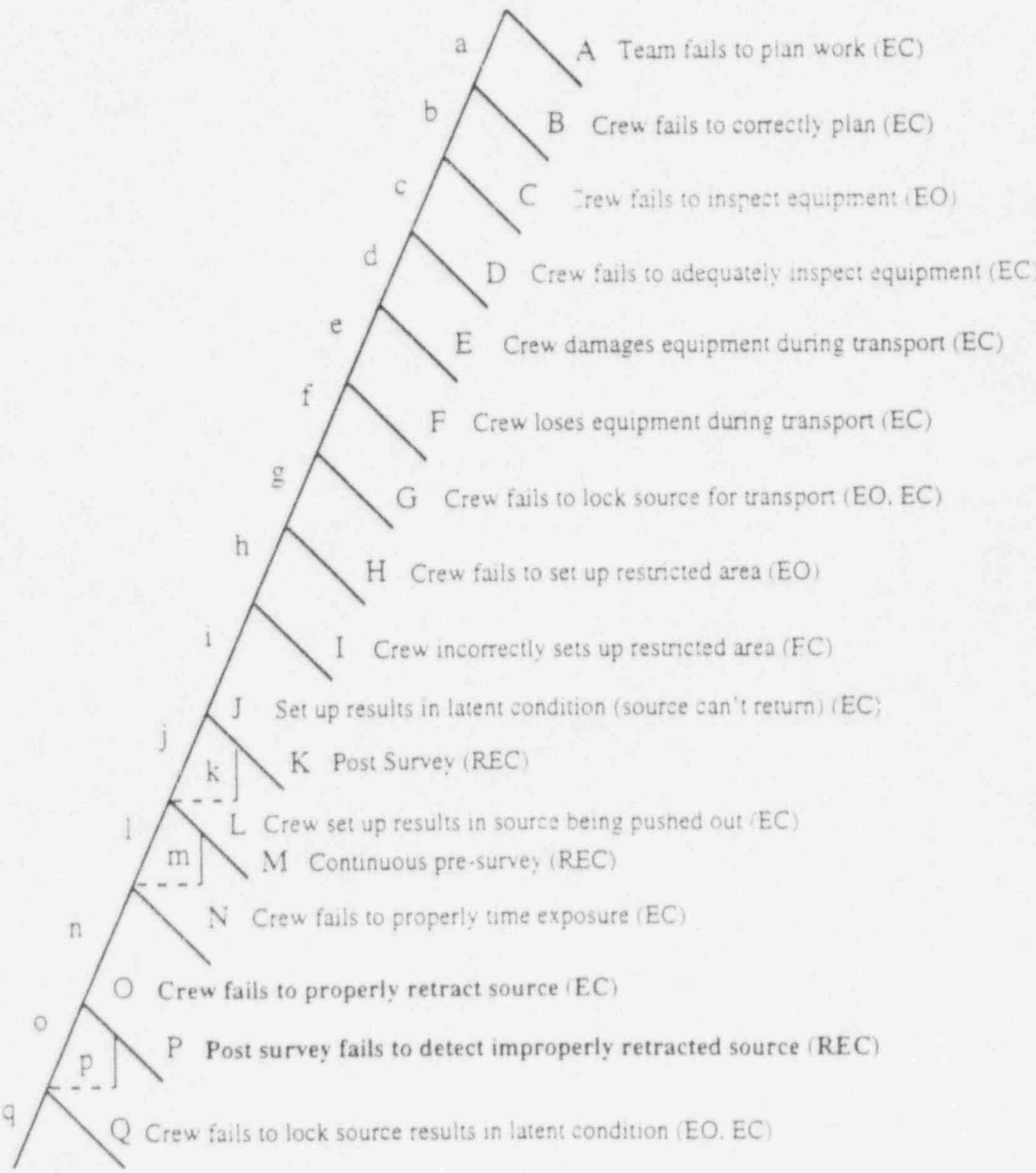
Record of incident placed in employee's file.

Appendix B
Section 14

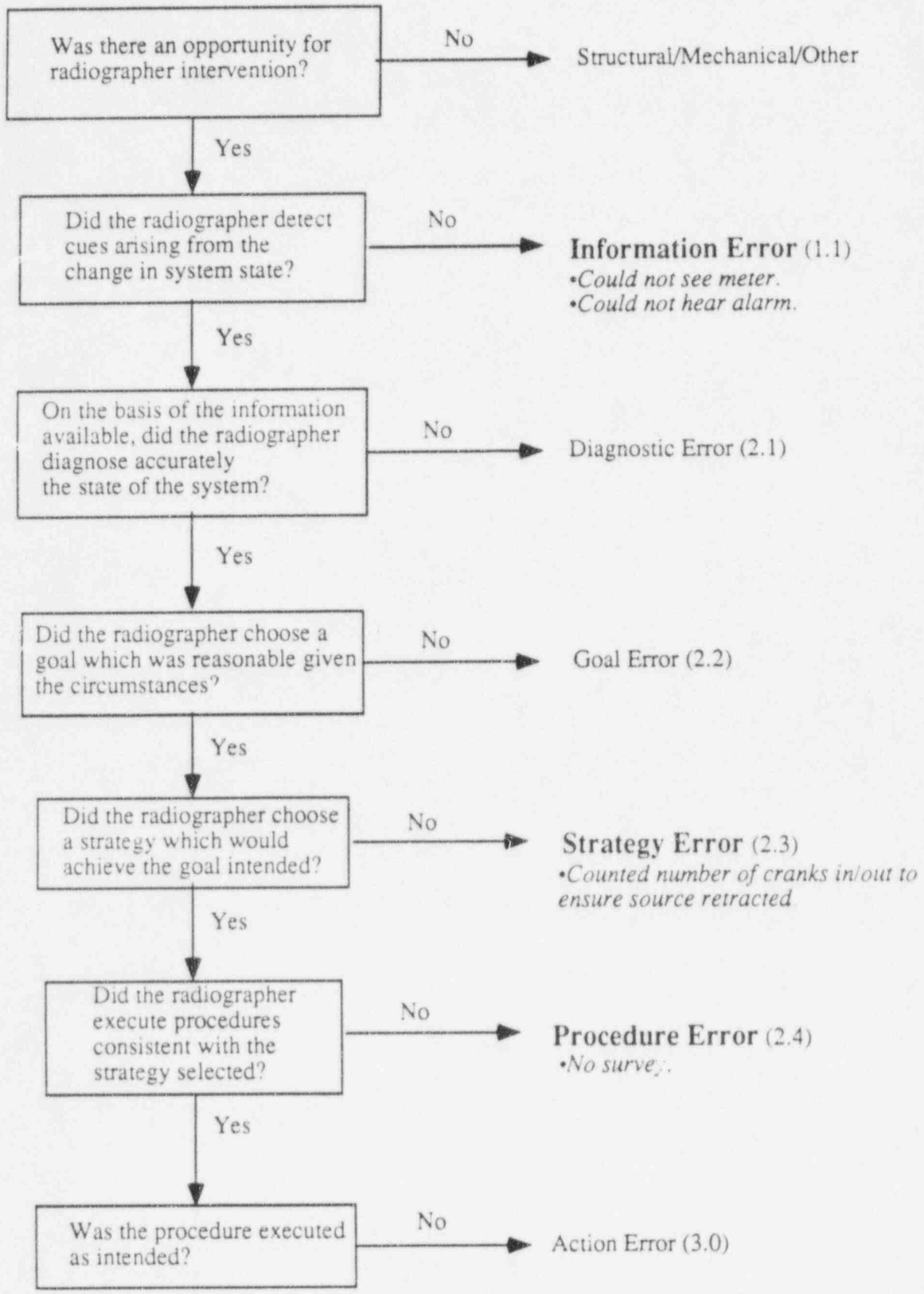
14

Person	operation	equipment
A/B	radiographer (A) and assistant (B) were x-raying welds on a pipeline	
A? B?	counted number of forward rotations of crank for source to reach end of guide tube	
A/B	performed last x-ray of the day	
A? B?	counted same number of backward rotation of crank to verify that source had returned to shielded position	crank, source, camera
A	locked camera	
A	curled guide tube back over the camera handle	
A	handed camera, guide tube, and control cable to assistant	camera, guide tube, control cable
A	(failed to survey camera and guide tube because it was 1730, getting dark, and he could not read his meter	camera, guide tube, survey meter
A	relied on audible radiation alarm to indicate unshielded source	audible alarm
A	heard audible alarm when he returned to pipe to remove film (didn't hear it earlier because of tractor noise)	audible alarm
A	shouted that source was unshielded	
A/B	left immediate area	
A/B	notice that pocket dosimeters were off scale	
A	couldn't return source to shielded position (when ?)	source
A? B?	told other pipeline workers of problem	
others	other workers left area	
B	stayed with unshielded source	
A	went to town	
A	called supervisor (C) for help	
C	found camera locked on source cable to that source could not be returned to shielded position	camera, cable, source, lock
C	unlocked camera	
C	pulled source into shielded position	
?	RSO told of incident later that evening	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982) 14



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• End of day • Getting dark • Relied on audible alarm • High noise in area obscured alarm cues • Camera can lock with source exposed	Procedure →	Failed to retract source Failed to survey after each exposure	Radiographers handled camera with source locked in exposed position.
	Strategy Error →	Counted crank revolutions as method to confirm source retraction	

OUTCOME

Radiographer and Assistant
Possible exposure

• 2.3 REM hands (calculated)

CORRECTIVE ACTIONS

Established incentive plan to emphasize need for good work practices.

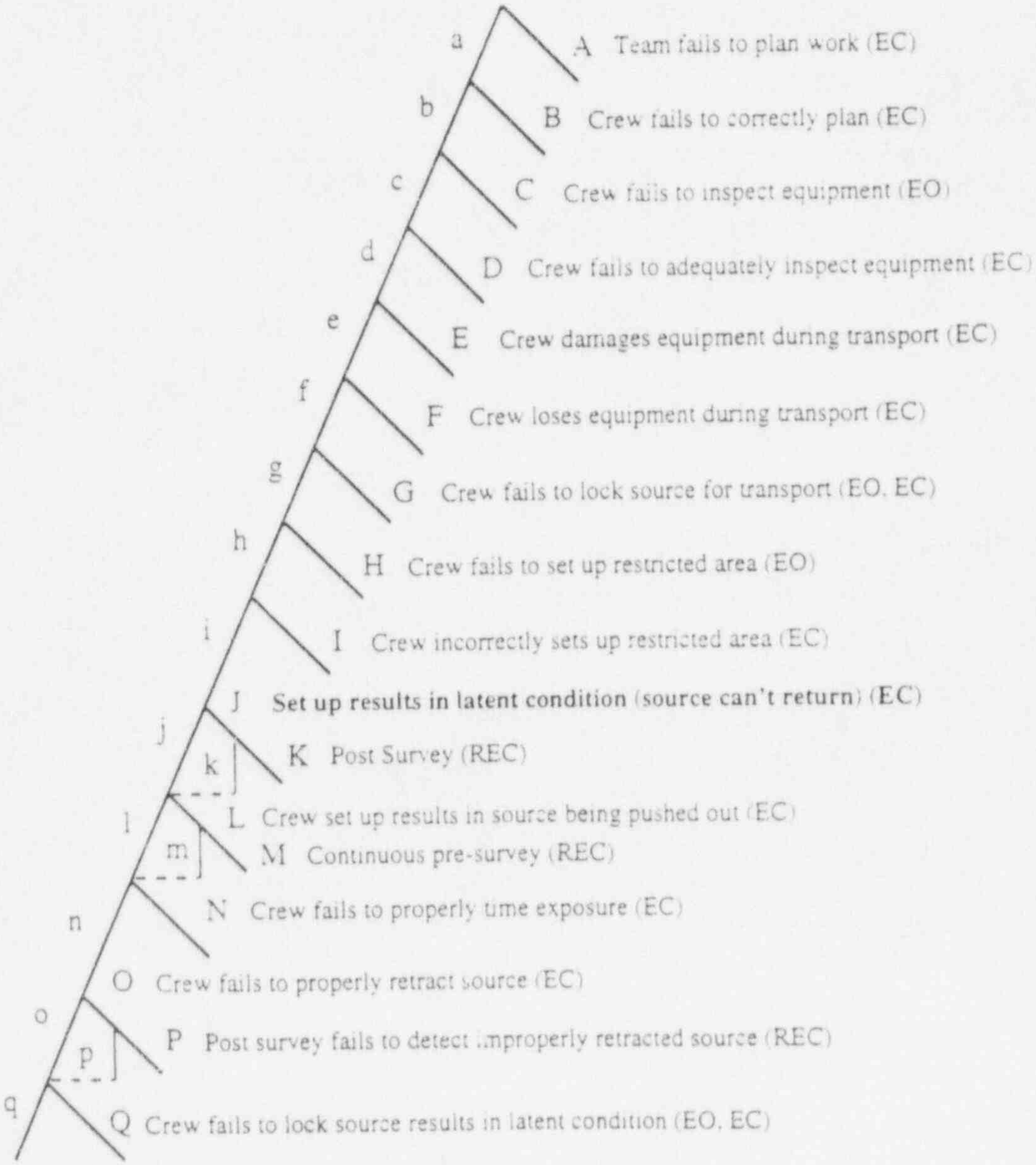
Memo to all personnel to review radiation survey section of operating and emergency manual.

Appendix B
Section 15

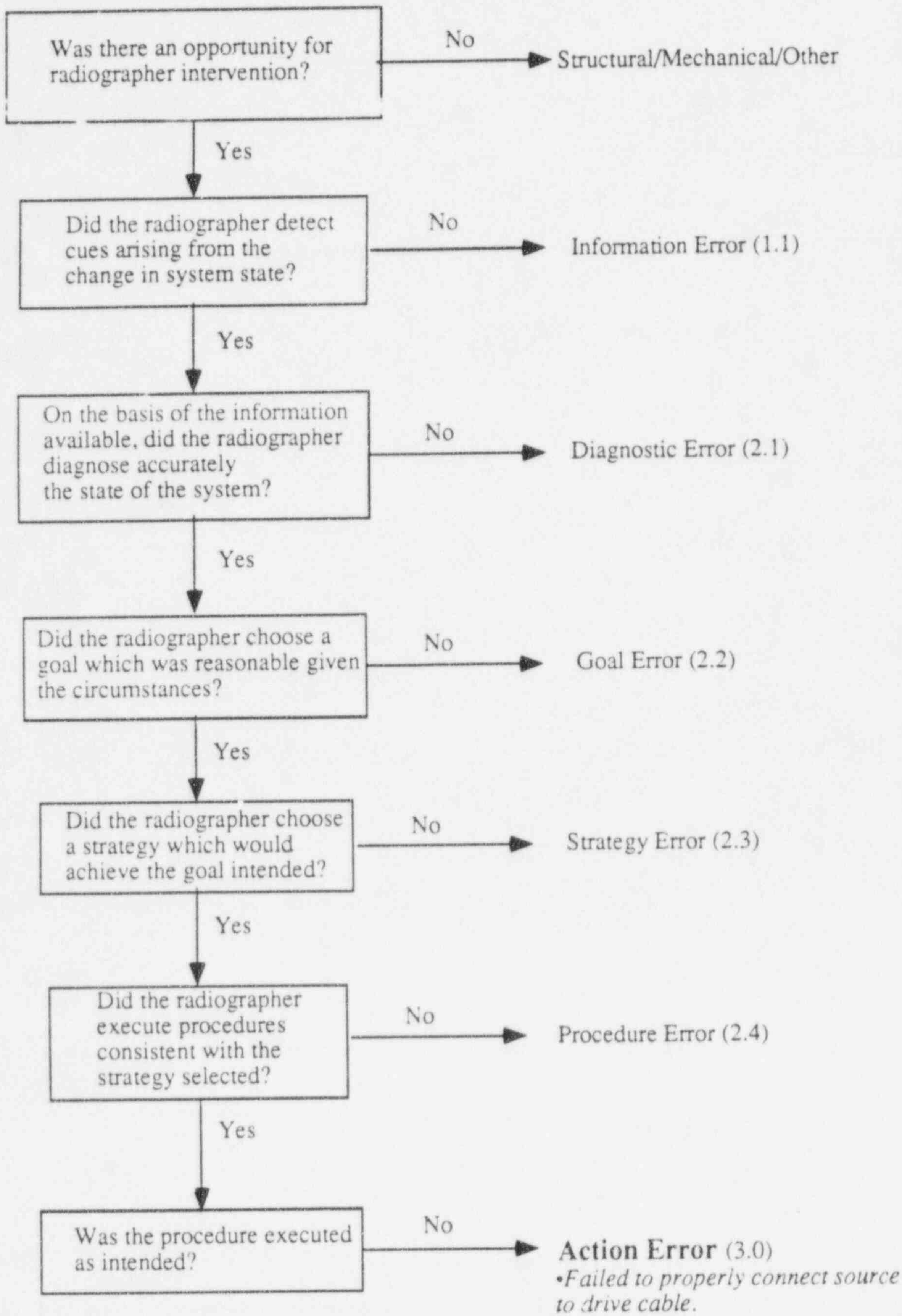
15

Person	operation	equipment
A	licensed radiographic inspector (A) was performing routine radiographic inspection	
A	started to screw the drive cable connect ons together	drive cable
A	pushed cable back into the housing without using the crank to pull it in	cable, housing, crank
?	source became hung up	source
B	radiographic assistant (B) called RSO (C) to report incident	
C	RSO arrive at site	
C	surveyed area in question	
?	containment area was enlarged	
C	carried lead shot into the vessel where the source was located	
C	located source within source tube	
C	covered source with one bag of lead shot	
C	disconnected source tube from the camera	
C	picked up source tube	
C	ran source into collimator, which was sandwiched between two bags of lead shot	
C	disconnected source tube from collimator	
C	hooked source tube back up to camera	
C	drove drive cable through source tube to collimator	
C	hooked source back up	
C	cranked source back into shielded position in camera	
C	reconnected everything correctly	
C	cranked source into and out of collimator 5 times without incident	
C	locked source	
C	continued investigation	
C	recreated the incident and established exposure to hands and extremities	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982) 15



Error Influences & Effects

PSFs	ERROR MECHANISMS		UNSAFE ACTIONS	UNRECOVERED EVENT
• Possibly inadequate training	Action	→	Improper connection of source pigtail and drive cable	Disconnected source lodged in guide tube.

OUTCOME

RSO exposure during retrieval

• 3.26 REM hands

(Radiographer exposure
• 25 mrem whole body)

CORRECTIVE ACTIONS

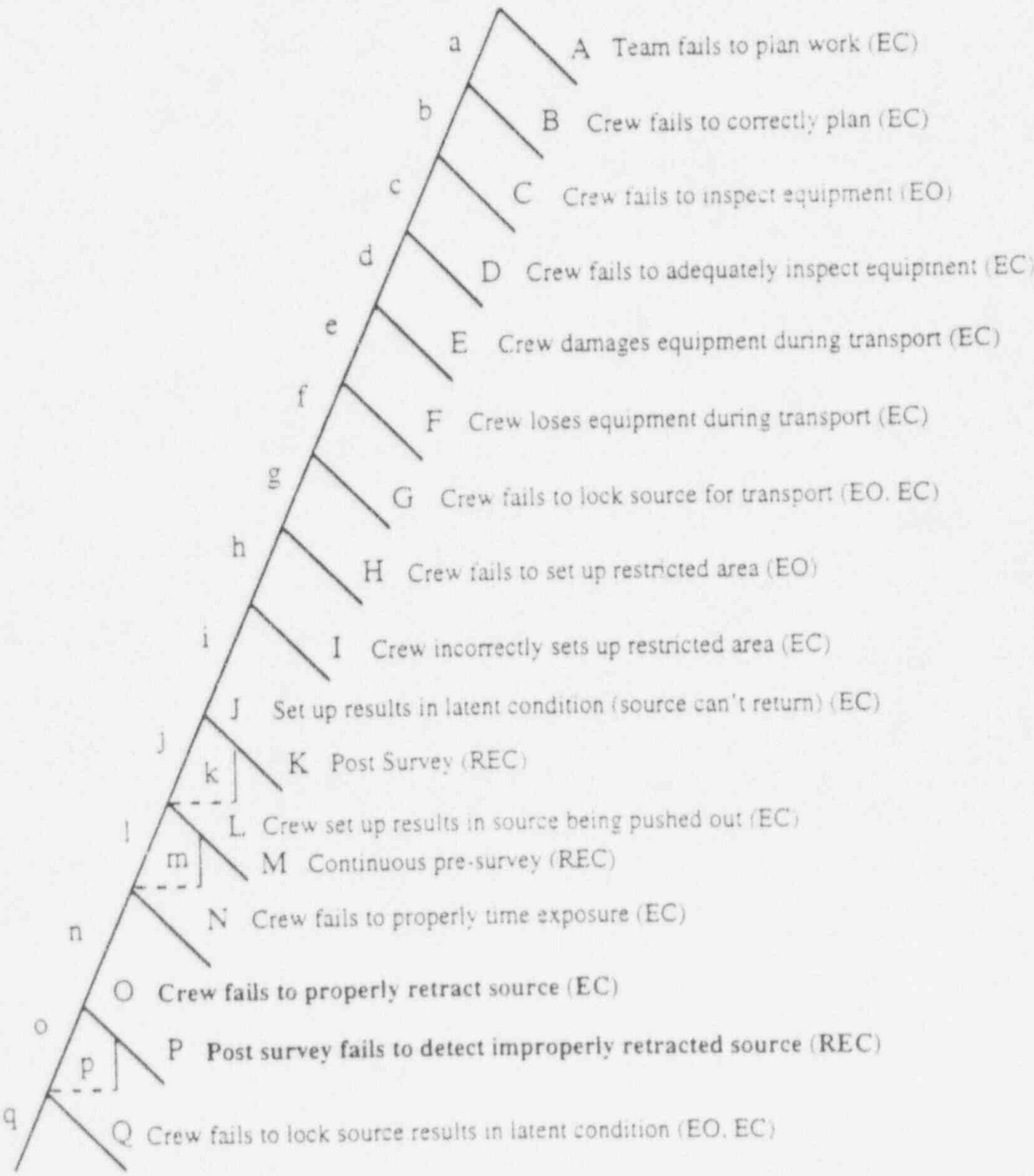
Instructed radiographer on proper source connection; observed radiographer connecting/disconnecting source before allowing him to return to work.

Appendix B
Section 16

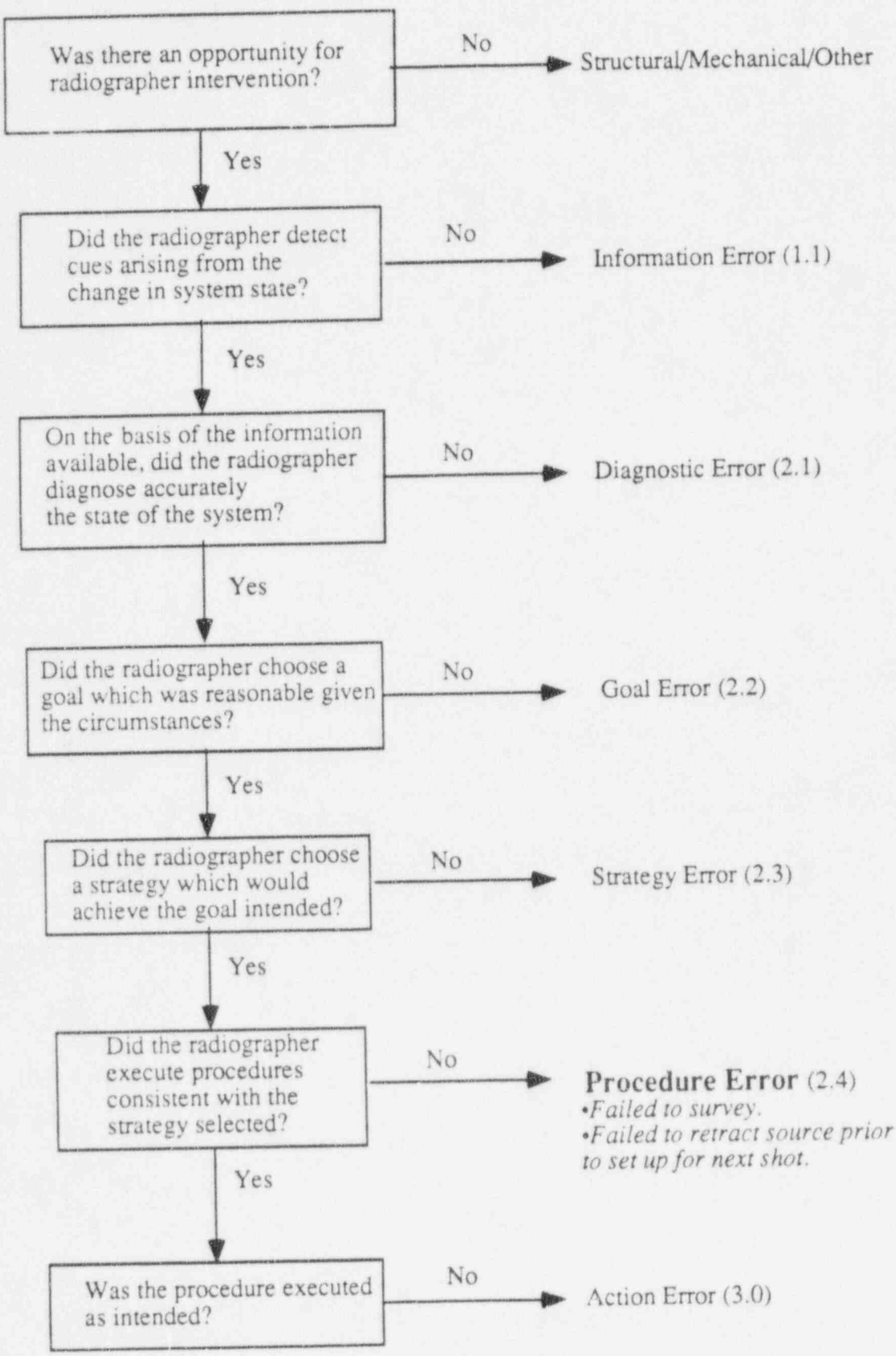
16

Person	operation	equipment
A	walked into shooting bay (permanent radiographic installation)	
A	got camera out of storage cabinet	
A	set up for shot	
A	walked back to crank out site	
A	cranked out source in order to locate and rope off the restricted area boundary	crank out, source
A	went outdoors to survey and locate the restricted area boundary	
A	returned to crank out site	
A	set down survey meter	
A	completed area survey form	
A	for unknown reasons, did not retract source to shielded position	source, camera
A	walked back into shooting bay	
A	set up next shot (hands very close to source)	
A	returned to crank to expose source	
A	realized source was already out (while he had set up shot)	source
A	returned source to shielded position	
A	surveyed area	
A	secured source	
A	locked storage area	
A	checked pocket dosimeter (off scale)	pocket dosimeter
A	left building	
A	notified RSO	
A	gave RSO dosimeter and film badge	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• No radiation alarm in shooting cell	Procedure	Failed to return source to shielded position	Radiographer failed to retract source after setting up boundaries using a procedure requiring the source to be exposed.
		Left survey meter on ground near crank while entering the shooting cell	
		Failed to survey to verify source returned to shielded position	

OUTCOME

Radiographer exposed

• 1.66 REM deep dose

CORRECTIVE ACTIONS

Radiation alarm installed in shooting cell.

Radiographer reinstructed on proper use of survey meters.

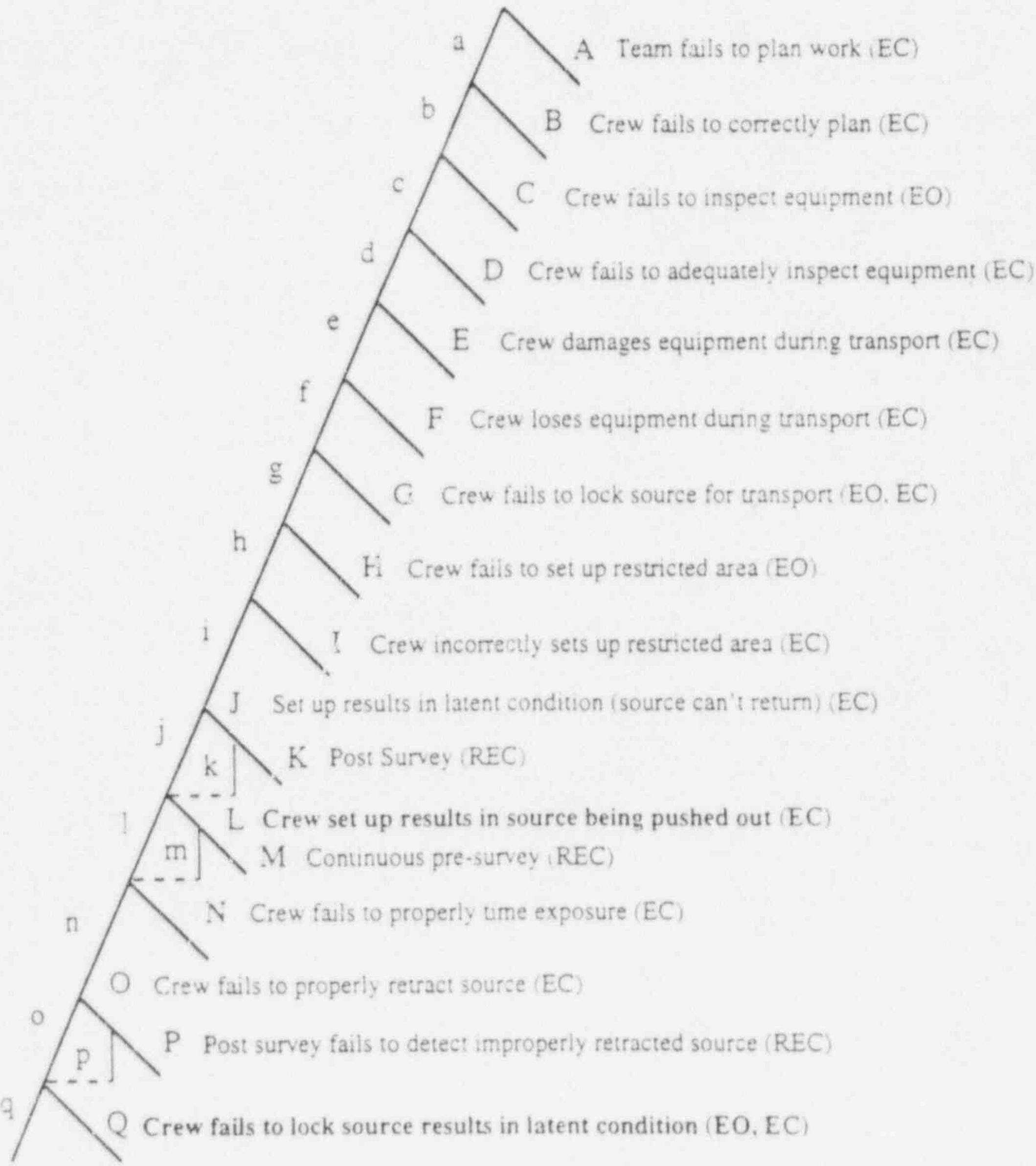
Safety meeting held with all radiographers.

Implemented use of alarming ratemeters.

Appendix B
Section 17

Person	operation	equipment
?	restricted area set up	
A	successfully performed first of ten planned radiographs	
A	cranked source to shielded position	
A	surveyed camera and guide tube	
A	rotated selector ring to "lock" position	
A	key locked camera	
A	removed key	
A	went to another area of plant to have exposed film developed	
?	film analyzed by technicians	
A	returned to radiographic area	
A	set up and conducted second radiograph	
A	cranked source back into shielded position	
A	performed necessary surveys to assure retracted source	
A	failed to rotate camera selector ring to "lock" position (according to re-enactment; A said he locked camera after every exposure)	camera selector ring
A	repositioned guide tube for third radiograph (involved moving camera about 12", which in turn apparently allowed the source to move to an unshielded position)	guide tube, source
A	performed third radiograph	
A	returned source to shielded position	
A	surveyed camera and guide tube	
A	placed camera selector ring in "lock" position	
A	key locked device	
A	delivered second and third radiographs to the dark room	
A	checked pocket dosimeter - offscale (time approx 0130)	dosimeter
A	re-zeroed dosimeter (assumed dosimeter drifted or was jarred off scale)	dosimeter
A	continued radiographic operations, completing the remaining seven planned radiographs	
A	checked dosimeter after each of the remaining seven exposures - no additional exposure noted	
A	stopped work (time approx 0300)	
A	notified ARSO (B) the next morning, several hours after it was noted off scale (time approx 0730)	

Event Tree for Generic Radiography



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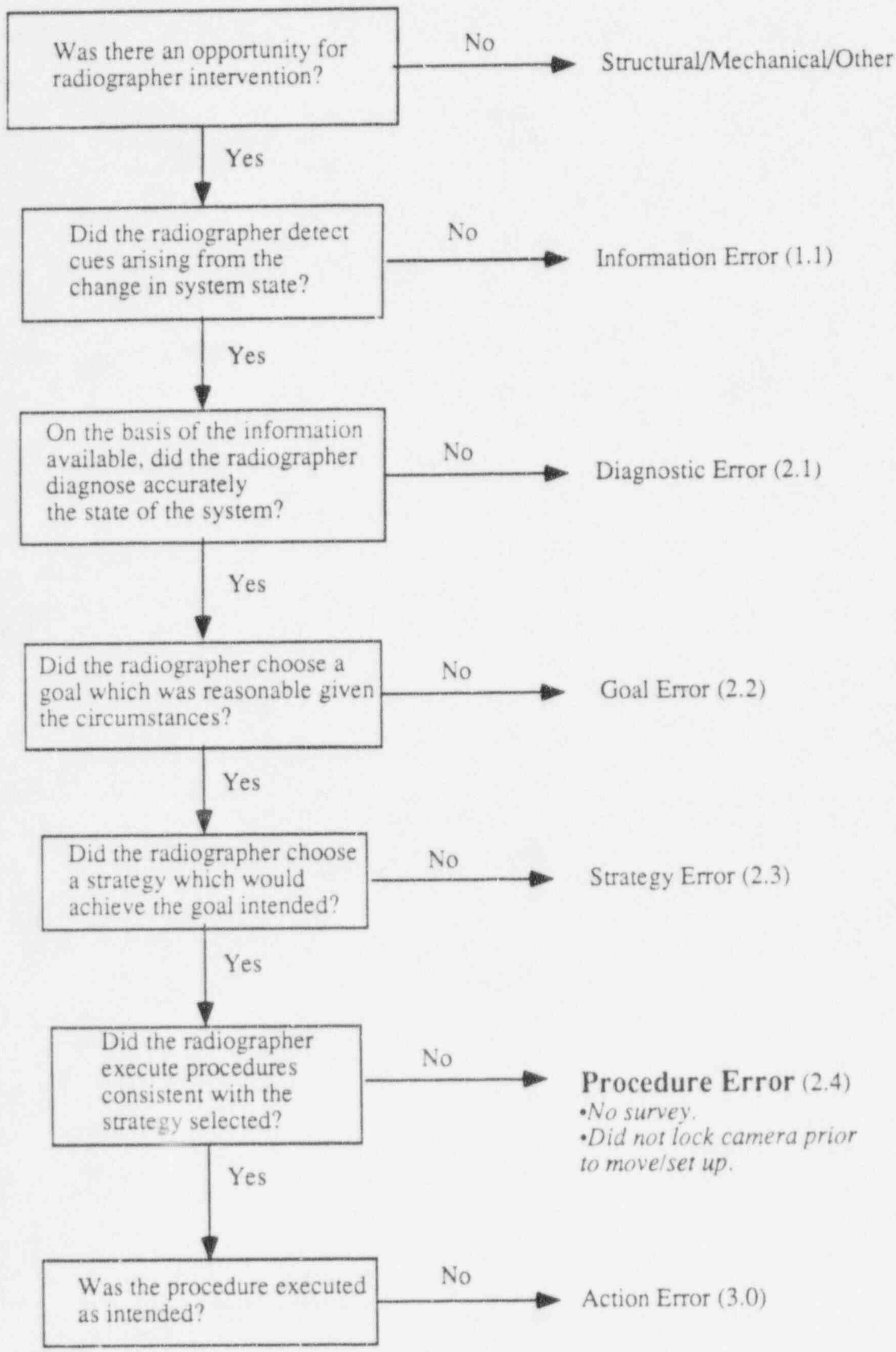


Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Working alone • Midnight	Procedure	Left camera unlocked after exposure Moved unlocked camera 12 inches Failed to survey	Radiographer moved camera without locking source in shielded position.

OUTCOME

Radiographer exposed

- 9[illegible] REM whole body

CORRECTIVE ACTIONS

Radiographer's certification suspended pending retraining and testing.

All licensee radiographers notified of incident and requirement to follow procedures.

Revised performance reviews to include observation reports.

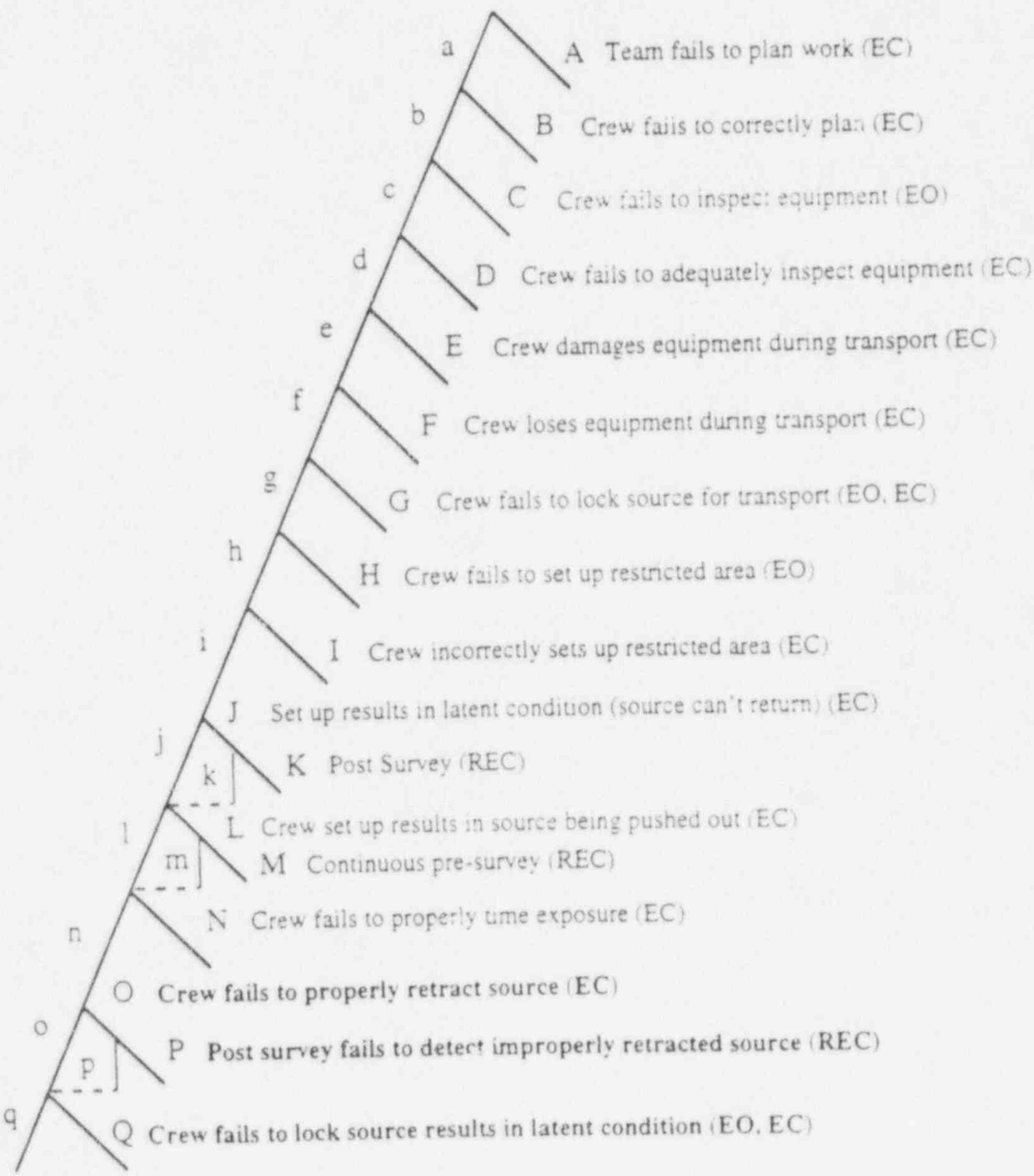
Graduated disciplinary action for violations with safety significance

Appendix B
Section 18

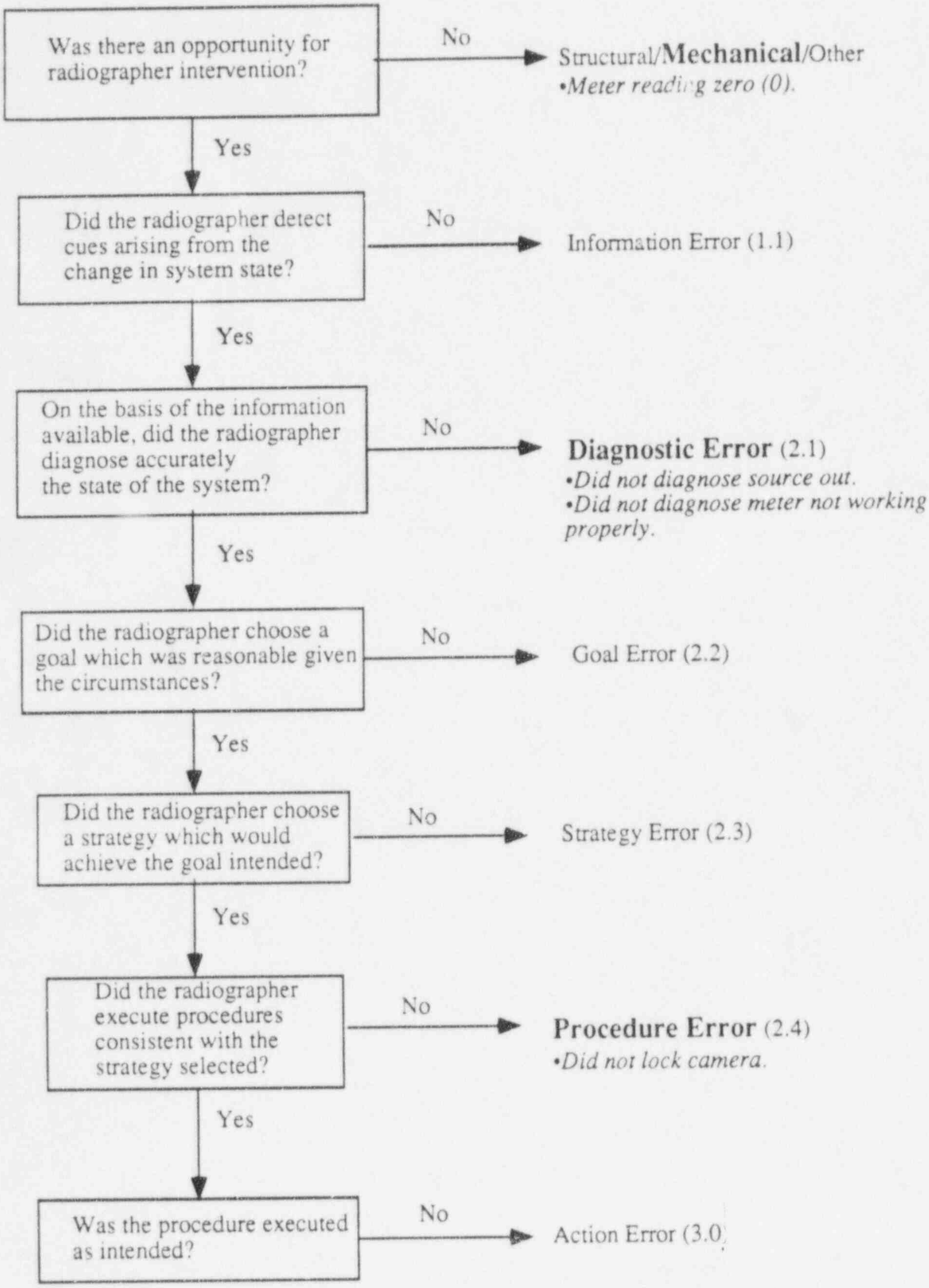
18

person	operation	equipment
A	radiographer (A) made weld exposure	
A	cranked source in	
A	looked at camera sideways	
A	observed green flag appeared to be out (locked position)	camera lock flag
A	observed survey meter reading 0	survey meter
A	approached camera with survey meter in hand	
A	surveyed camera	
A	surveyed source tube	
A	observed survey meter reading 0	survey meter
A	began to set up for next shot with camera behind him, 12-24" from his side	
A	removed magnetic stand from the tank	
A	placed magnetic stand down on the next shot	
B	assistant (B) started to walk up to the film	
B	noticed survey meter needle at full deflection and selector switch on x10 scale	survey meter
B	yelled that his meter was pegged out	survey meter
B	came out of tank where they were x-raying the inside of the wall	
A	backed up on crank control	
A	shook survey meter	survey meter
A	observed meter pegged out on x10 scale	survey meter
A	cranked back and forth (handle went about 1/4 turn and locked, apparently hung up on a kink in the tube)	crank control
A	realized overexposed	
A	stopped work	
A/B	notified RSO (C)	
C	told A not to re-enter the radiation area until his film badge could be processed	
B	finished x-ray job	
-	camera returned to manufacturer for complete examination	
-	camera determined to be fully operable	

Event Tree for Generic Radiography



Information Processing Failures (adapted from O'Hare et al., 1994; Rasmussen, 1982)



Error Influences & Effects

PSFs	ERROR MECHANISMS	UNSAFE ACTIONS	UNRECOVERED EVENT
• Last shot of day		Failed to realize survey meter malfunctioning	Radiographer failed to recognize faulty meter when surveying camera with source exposed.
	Diagnostic Error		
		Failed to ensure source locked in shielded position	
	Procedure		
		Failed to retract source	

OUTCOME

Radiographer exposed

• 7.77 REM whole body

CORRECTIVE ACTIONS

Camera sent for examination (determined fully operable)

Appendix B
Section 19

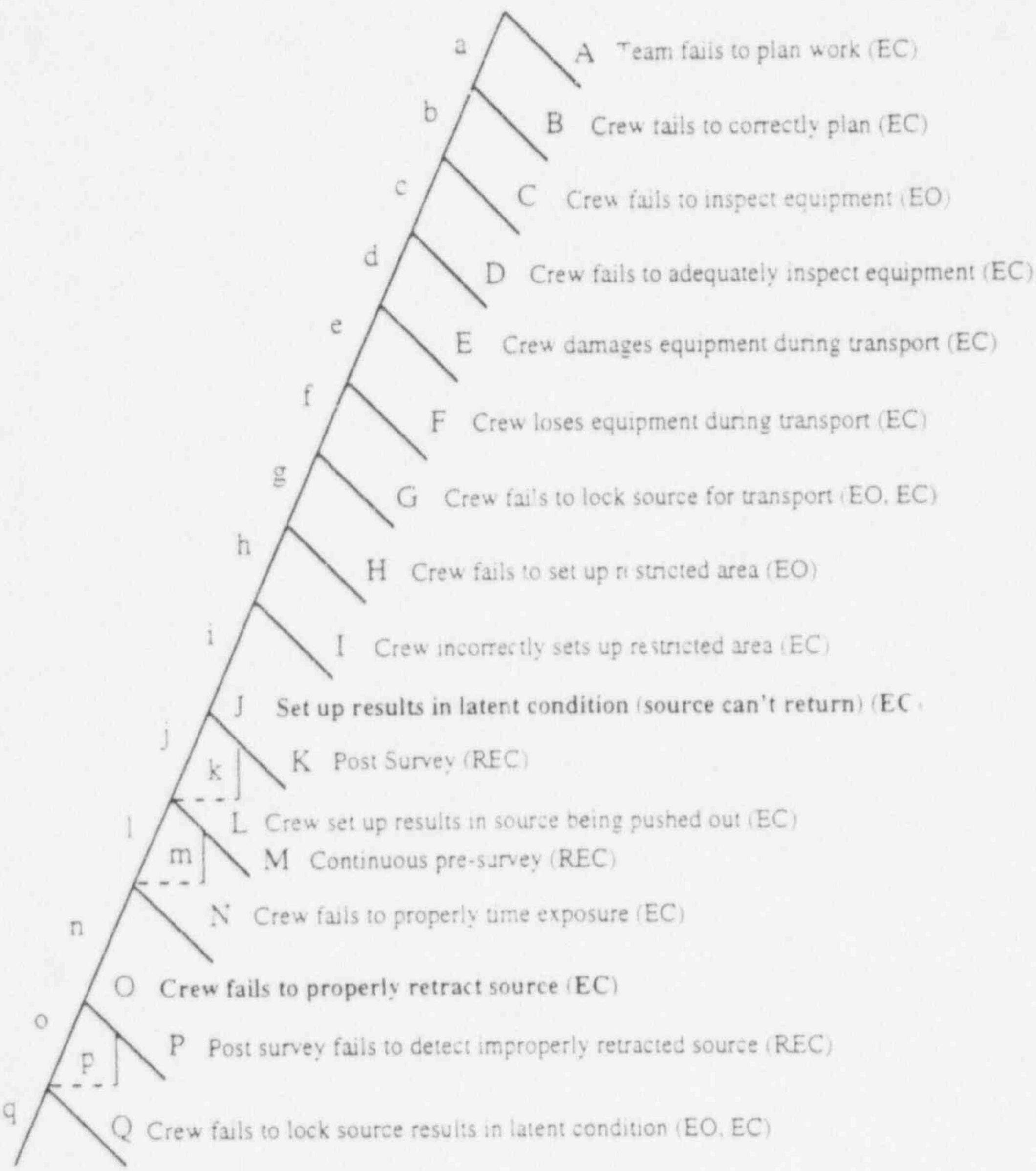
19

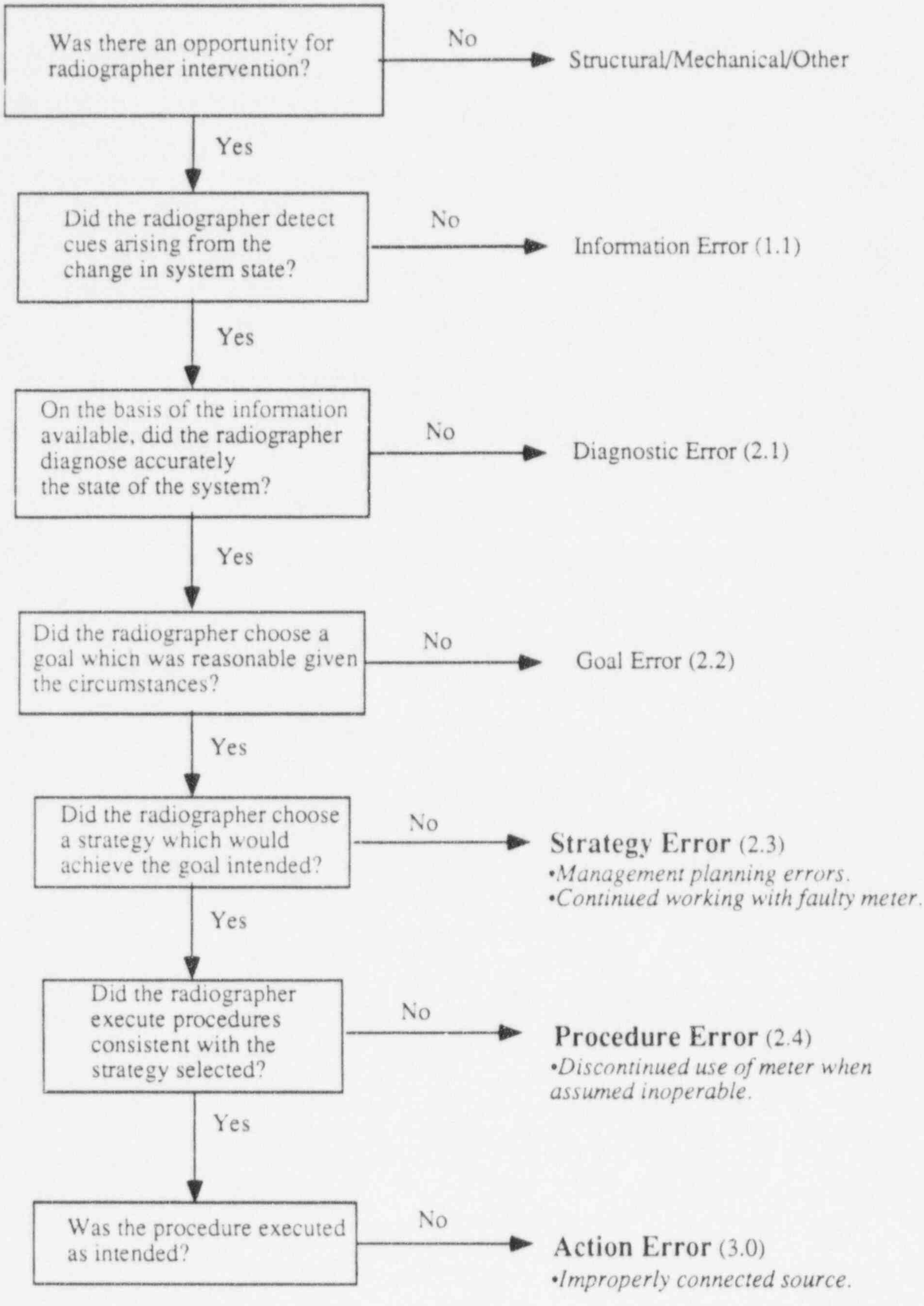
Person	operation	equipment
D	asked for volunteers to work that night	
B	didn't volunteer	
D	deciphered silence as "yes"	
D	designated B as assistant	
B	became film runner after 1st day as assistant	
D	decided to shoot x-rays on 5th floor of boiler	
D	took B along as temporary assistant	
F	new employee (F) became film runner	
B	B became assistant	
D	set up radiation area boundaries	
A/B/E/G	confirmed no unmonitored personnel within boundaries	
A/B/E/G	set up first exposure	
D	notified control room and A and E of clearance for operation start up	
A	notified D of survey meter low battery reading	
D	suggested A send B for new meter or he (D) would bring one as soon as possible	
A/B	continued to work	
A/B	source tube disconnected at least once	source tube
B	thought he connected source to drive cable	source, drive cable
B	cranked source out for first exposure	
B	could not get source to retract because of improper connection	source
A	changed film	
B	read survey meter pegged off scale (says it was after second exposure)	survey meter
B	read survey meter (pegged off scale) after third exposure	survey meter
B	no longer used meter	survey meter
B	heard something fail during approximately 4th-5th exposure (recalled this later)	source
A	requested more film and another meter of D after 1/2 to 1-1/2 hour more work	
D	took more film and another meter to A	
D	called A to say eight of eleven films were underexposed	
A	radioed something was wrong with the area	
E	went to assist	
E	reported high radiation levels in A's work area	
E	reported crank out control cables not moving far enough	
A/B	stopped work	

all?	evacuated boiler room	
D	called RSO	
D/E	assessed source in unsafe position	
C	RSO (C) received call about incident	
C	responded	
C	interviewed A and B	
C	surveyed work area (3rd floor of boiler)	
C	confirmed high radiation reading inside boiler	survey meter
C	checked camera (locked with source tube connected)	
C	disconnected source tube	
C	checked exit point of camera (no source)	
C	checked inside of source tube (no source)	
C	took camera to floor level	
C	placed 4'x 8' plywood on floor for possible source drop	
C	returned to work area	
C	retrieved source tube	
C	dropped source tube to plywood on floor (no source)	
C	returned to floor	
C	surveyed source tube (no high radiation) - source not in source tube or camera	
D	another person continued to keep area secure	
C	returned to crew area	
C	discussed incident with the two people involved (A/B)	
C	reviewed exposed films	
C	decided 4th exposure was most likely time for source to fall out during moves	
C	returned to exposure area	
C	discussed situation with D & E	
C	learned source was in area where operations has been conducted	
C	retrieved source	
C	secured source inside camera	

A = "radiographer", really an assistant, received 18 rem
B = "assistant" to B, though not trained for this, received 2 rem
C = RSO
D = radiographer?
E = radiographer
F = "assistant", though not trained for this
G = "assistant" to E, though not trained for this

Event Tree for Generic Radiography




Was there an opportunity for radiographer intervention?
No
Structural/Mechanical/Other
Yes
Did the radiographer detect cues arising from the change in system state?
No
Information Error (1.1)
Yes
On the basis of the information available, did the radiographer diagnose accurately the state of the system?
No
Diagnostic Error (2.1)
Yes
Did the radiographer choose a goal which was reasonable given the circumstances?
No
Goal Error (2.2)
Yes
Did the radiographer choose a strategy which would achieve the goal intended?
No
Strategy Error (2.3)
•Management planning errors.
•Continued working with faulty meter.
Yes
Did the radiographer execute procedures consistent with the strategy selected?
No
Procedure Error (2.4)
•Discontinued use of meter when assumed inoperable.
Yes
Was the procedure executed as intended?
No
Action Error (3.0)
•Improperly connected source.

Error Influences & Effects

PSFs

- Poor lighting
- Source pigtail small, fell into grated flooring
- Inadequate training
- Heavy workload (extended workweek)

ERROR MECHANISMS

Strategy

Procedure

Action

UNSAFE ACTIONS

Management assigned untrained personnel to do radiography

Continued to work with faulty survey meters

Discontinued use of meters and continued working

Improper connection of source to drive cable

UNRECOVERED EVENT

Multiple unsafe actions performed by unqualified crew.

OUTCOME

Assistant radiographers exposed

- 2.1 REM whole body
- 18.5 REM whole body

CORRECTIVE ACTIONS

Require alarming ratemeters.

Rescheduled safety classes for all personnel.

More unannounced checks

Appendix C

Analysis Summary Table

Appendix C

Analysis Summary Table

EVENT	ASSUMPTIONS (explicit assumptions made regarding event)	ERRORS (1st line - Letter=failure path(s) on generic HRA tree) (2nd line - Information Processing Failures identified)	PSFs	UNKNOWNS (Insufficient information available in reports)
1	Latent error=incorrect source pigtail Goal=protect public safety/health	"O" Mechanical *(incorrect pigtail)* Strategy *(continued w/o RSO)(used hands to move source back to shield)* Action *(put wrong end back into camera)*	Dark Trench Muddy	Exact sequence and timing=? "Old" alarm ratemeter Source connector problems
2	Latent error=hardware (pins in lockbox failed)	"D" Mechanical *(pins failed)* Diagnostic *(failed to inspect pins in locking mechanism)* Strategy *(manual check of cable)* Procedure *(didn't survey)*	Low light Source, connector & INC hookup look similar	
3	Latent error=set up results in magnetic stand falling (due to placement/dirty surface/ etc.)	"J" "O" Strategy *(set up error = stand placement)*	Working inside tank	Possible need for stronger magnets?
4	Latent failure=crimp in cable (source can't extend/retract)	"C" Mechanical *(crimp in cable)* Diagnostic *(cable not inspected)* Strategy *(removed tube to locate source)(turned off alarm)* Procedure *(didn't call RSO)*	-	-
5	Latent error=Rad A leaves area (strategy/procedure error)	"O" "P" Strategy *(Rad A leaves trainee unsupervised)* Goal *(working w/o supervision)* Procedure *(no survey)* Action *(didn't fully retract source to shielded position)*	Trainee "speed up job"	Camera/source "hang-up" problem?
6	No continuous survey during camera unlock and adjustment	"L" Strategy *(moved camera after unlocking during set up)*	11 hours into the shift	-

EVENT	**ASSUMPTIONS** (explicit assumptions made regarding event)	**ERRORS** (1st line - Letter=failure path(s) on generic HRA tree) (2nd line - Information Processing Failures identified)	**PSFs**	**UNKNOWNS** (Insufficient information available in reports)
7	Latent failure=camera can lock with source exposed Rad level high enough to set off alarming meter (if turned on)	"L" "M" Procedure *(didn't survey)(ratemeter off)* Strategy *(moved camera to lock it)*	Working on scaffolding Turned off alarm ratemeter during paperwork to conserve battery power Camera locks with source exposed	-
8	Procedure for tube set up not specific Survey meter not initially working Bend in tube prevented retraction	"J" "O" "P" Information *(couldn't hear)* Action *(set up with bend in tube)* Mechanical *(meters off scale)*	High noise in area Wearing ear protection prevented hearing alarming ratemeter	-
9	(NONE)	"C" "D" Diagnostic *(status of meter)(location of source)* Mechanical *(meter at 0)* Procedure *(failed to lock)* Action *(failed to fully retract source)*	-	Equipment problems or setup error?
10	Meter malfunction/battery problem	"D" "Q" Mechanical *(meter at zero)* Diagnostic *(meter at zero)* Strategy *(looked into camera port)(failed to check crank after tripping over it)* Procedure *(didn't lock camera)*	Last of ten shots Anxious to "wrap up" work	
11	Source not fully retracted/not locked Strategy error in set up (stability on ladder)	"O" "P" "J" Strategy *(setup camera on ladder)* Procedure *(no survey)* Action *(source not retracted)*	-	-
12	Failed to turn on alarming ratemeter	"O" "P" Goal *(assistant working w/o supervision)* Procedure *(no survey) (dosimeter not turned on)(didn't lock camera before moving)*	Inadequate training Inadequate experience	Calibration of dosimeter? (film badge lost)
13	(NONE)	"H" Diagnostic *(shielding in reboiler, falsely assumed not a restricted area)*	-	-

EVENT	ASSUMPTIONS (explicit assumptions made regarding event)	ERRORS (1st line - Letter=failure path(s) on generic HRA tree) (2nd line - Information Processing Failures identified)	PSFs	UNKNOWNS (Insufficient information available in reports)
14	Latent equipment problem=camera can lock with source exposed	"O" "P" Information *(couldn't see meter)(couldn't hear alarm)* Strategy *(counting cranks in out to confirm source retracted)* Procedure *(no survey)*	Last shot of day Getting dark Loud noise	-
15	(not modelling RSO) (Outcome = 3REM to RSO in recovering source)	"J" Action *(fail to connect source to drive cable)*	Inadequate training?	How did Radiographer know source was not retracted? (no info provided in report)
16	According to procedures, source cranked out to locate restricted area (procedures were followed)	"O" "P" Procedure *(didn't survey)(didn't retract source)*	No radiation alarm in shooting cell	Questionable logic behind procedure for calculating area boundaries
17	Did not lock camera (NRC belief)	"L" "Q" Procedure *(didn't survey) (didn't lock camera)*	Working alone Between 2330 and 0130	Camera can't be locked unless source is fully retracted
18	Didn't fully retract source Misinterpreted or didn't look to see flag positions	"O" "P" "Q" Mechanical *(meter at zero)* Diagnostic *(meter at zero)(source out)* Procedure *(didn't lock camera)*	Last shot of day	
19	Management errors in work planning/ assignment of responsibilities and providing adequate training	"J" "O" Action *(improperly connected source)* Strategy *(management work planning errors)(continued working with faulty meter)* Procedure *(discontinued use of meter, continued to work)*	Poor lighting Inadequate training Heavy workload / extended work week	-

Appendix D

Generic HRA and Information Processing Failures Compiled Data

Appendix D

Generic HRA and Information Processing Failures Compiled Data

Generic HRA Trees

FAILURE PATH(S):

Failed to properly retract source ("O")

53% (10/19)

(Events #1,3,5,8,11,12,14,16,18,19)

"O" is almost a subset of "J" (i.e., the failure to properly retract the source results in a latent condition where the source can't be returned). Taken together, these two make up 58% of the cases, (#1,3,5,8,11,12,14,15,16,18,19). Cases #3, 8, 11, and 19 were listed as having both of these causes. Now that these cases have been categorized, the remaining ones might show overlap if they were reviewed again with this in mind.

Failed to do continuous pre-survey ("M") or post-survey ("K", "P")

42% (8/19)

(Events #5,7,8,11,12,14,16,18)

All of these were grouped together since they all were failures to survey (i.e., post-survey after a set up resulting in latent conditions where the source couldn't return, continuously when the set up resulted in the source being pushed out, and post-survey when the source was not properly retracted). The location of failures to survey needs to be reconsidered for the generic tree, since there additional places where it could occur (e.g., crew fails to lock source results in latent condition).

Set up results that led to latent condition (source can't return) ("J")

26% (5/19)

(Events #3,8,11,15,19)

Failed to inspect ("C"), or adequately inspect ("D"), equipment

21% (4/19)

(Events #2,3,9,10)

These are grouped together since, in most cases, it is not stated that the crew actually inspected the equipment prior to using it and assumptions had to be made. Two cases were judged to have "failed to inspect" and three were judged to have "failed to adequately inspect." One of those cases was put into both categories. The generic tree should be modified to reflect this lack of information or future investigations should address this issue specifically whenever there is an equipment failure (e.g., camera failure, battery problems, crimp in guide tube, etc.).

Set up results that led to source being pushed out ("L")

16% (3/19)

(Events #6,7,17)

Failed to lock source, resulting in latent condition ("Q")

16% (3/19)

(Events #10,17,18)

"Q" is almost a subset of "L" (i.e., the failure to lock the source results in a latent condition that could cause the source to be pushed out). Taken together, these two make up 26% of the cases (#6,7,10,17,18). In fact, case #17 was listed has having both of these causes.

Failed to set up ("H"), or correctly set up ("I"), restricted area

5% (1/19)

(Event #13)

These two were grouped together because, in the one case involving a restricted area, it was uncertain whether the elimination of the reboiler from the restricted area was a "failure to set up" or "failure to correctly set up".

Failed to plan ("A"), or correctly plan ("B"), work

0%

Damaged equipment during transport ("E")

0%

Lost equipment during transport ("F")

0%

Failed to lock source for transport (from warehouse to weld site) ("G")

0%

Failed to properly time exposure ("N")

0%

Information Processing Failures Model

INFORMATION PROCESSING FAILURE CATEGORIES

68% of events had procedure errors (13/19)

#2 -	failed to survey
4 -	didn't call RSO
5 -	failed to survey
7 -	failed to survey ratemeter off
9 -	failed to lock camera
10 -	failed to lock camera
11 -	failed to survey
12 -	failed to survey dosimeter not turned on failed to lock camera before moving it
14 -	failed to survey
16 -	failed to survey failed to retract source
17 -	failed to survey failed to lock camera
18 -	failed to lock camera
19 -	discontinued use of survey meter continued to work

58% of events had strategy errors (11/19)

#1 -	continued without RSO
	used hands to move source back to shield
2 -	manual check of cable
3 -	setup error
4 -	removed tube to locate source
	turned off alarm
5 -	radiographer left trainee alone
6 -	moved camera after unlocking during setup
7 -	moved camera to unlock it
10 -	looked into camera hole
	failed to check crank after tripping over it
11 -	set up camera on ladder
14 -	counted cranks out and in to determine if source retracted
19 -	management planning errors
	continued working with faulty meter

37% of events had action errors (7/19)

#1 -	put wrong end back into camera
5 -	failed to fully retract source to shielded position
8 -	set up with bend in tube
9 -	failed to fully retract source
11 -	source not retracted
15 -	failed to connect source to drive cable
19 -	improperly connected source

37% of events had mechanical errors (7/19)

#1 -	incorrect pigtail
2 -	pins failed
4 -	crimp in cable
8 -	meters off scale
9 -	meter at 0
10 -	meter at 0
18 -	meter at 0

32% of events had diagnostic errors (6/19)

#2 - failed to inspect pins
4 - cable not inspected
9 - status of meter (not working)
location of source
10 - meter at 0
13 - reboiler falsely assumed to be unrestricted area
18 - meter at 0
source out

11% of events had goal errors (2/19)

#5 - working without supervision
12 - assistant working without supervision

11% of events had information errors (2/19)

#8 - couldn't hear
14 - couldn't see meter
couldn't hear alarm

INFORMATION PROCESSING FAILURE CATEGORIES (subdivided into specific failure types

procedure errors

42% of procedures errors (8/19)

#2 - failed to survey
11 - failed to survey
17 - failed to survey
5 - failed to survey
16 - failed to survey
12 - failed to survey
7 - failed to survey
14 - failed to survey

26% of procedure errors (5/19)

#9 - failed to lock camera
12 - failed to lock camera
10 - failed to lock camera
17 - failed to lock camera

18 - failed to lock camera

16% of procedure errors (3/19)

#19 - discontinued use of survey meter
12 - dosimeter not turned on
7 - ratemeter not turned on

5% of procedure errors (1/19) for each of the following:

#16 - failed to retract source
4 - didn't call RSO
19 - continued to work

strategy errors

13% of strategy errors (2/15)

#6 - moved camera after unlocking during setup
7 - moved camera to unlock it

the following strategy errors could not be readily put into groups:

#1 - used hands to move source back to shield
1 - continued without RSO
2 - manually checked cable
3 - setup error
4 - removed tube to locate source
5 - radiographer left trainee alone
10 - looked into camera hole
11 - failed to check crank after tripping over it
11 - set up camera on ladder
14 - counted cranks out and in to determine if source retracted
19 - management planning errors
19 - continued working with faulty meter

action errors

43% of action errors (3/7)

#5 - failed to fully retract source to shielded position
9 - failed to fully retract source
11 - failed to retract source

29% of action errors (2/7)

#15 - failed to connect source to drive cable
19 - improperly connected source

the following action errors could not be readily grouped:

- #1 - put wrong end back into camera
- 8 - set up with bend in tube

mechanical errors

57% of mechanical errors (4/7)

- #8 - meters off scale
- 9 - meter at 0
- 10 - meter at 0
- 18 - meter at 0

the following mechanical errors could not be readily grouped:

- #1 - incorrect pigtail
- 2 - pins failed
- 4 - crimp in cable

diagnostic errors

25% of diagnostic errors (2/8)

- #10 - meter at 0
- 18 - meter at 0

the following diagnostic errors could not be readily grouped:

- #2 - failed to inspect pins
- 4 - cable not inspected
- 9 - status of meter (not working)
- 9 - location of source
- 13 - reboiler falsely assumed to be unrestricted area
- 18 - source out

goal errors

100% of goal errors (2/2)

- #5 - working without supervision
- 12 - assistant working without supervision

information errors

100% of information errors (3/3) involved sensory misinformation

- #8 - couldn't hear
- 11 - couldn't hear alarm
- 14 - couldn't see meter

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This report summarizes the methods, analyses, results, and conclusions drawn from a human performance evaluation of industrial radiography exposure incidents. The Nuclear Material Events Database (NMED) was used to identify radiography exposure events occurring between 1987 and 1994; 95 events were identified. A subset of the events was used for detailed analysis, including the application of several modeling tools. Each analysis technique is described in detail in this report, and completed analyses for the subset of exposure events are included in the appendices. Detailed analysis results were combined to indicate the types of errors involved in the radiography task, and how the errors might be characterized. Based on the analyses, suggestions were developed for how to address errors. Ideas for the use of training, equipment interface design, and job aids to improve performance are presented. To address the need for the collection of detailed incident information, an easy-to-use guide was developed and is included in this report.

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