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Occupational Safety Data and Casualty Rates for the Uranium Fuel Cycle

F. R. O'Donnell H. C. Hoy

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DEPARTMENT OF ENERGY

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Contract No. W-7405-eng-26

OCCUPATIONAL SAFETY DATA AND CASUALTY RATES FOR THE URANIUM FUEL CYCLE

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Prepared for
Assistant Secretary for Environment
Office of Environmental Assessment
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Department of Energy

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Date Published: October 1981

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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UNION CARBIDE CORPORATION
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ACKNOWLEDGMENTS

The collection of the data used in this report required the generous cooperation of many organizations and individuals. Although it is not possible to list all persons who contributed information, we would be remiss in not acknowledging the invaluable and considerable contributions of the following: J. Inzana of the Bureau of Labor Statistics; D. Redmon, D. Walker, G. Duhn, and L. Larson of the Mine Safety and Health Administration; B. C. Day of the Tennessee Valley Authority; R. Curry and J. Recht of the National Safety Council; W. Tarrant and W. F. Gay of the U.S. Department of Transportation; K. R. Baker and A. Kaufner of the U.S. Department of Energy; and K. Sommerfeld and B. I. V. Bailey of the Oak Ridge Gaseous Diffusion Plant.

The helpful suggestions and recommendations of H. Inhaber, A. P. Watson, and E. L. Etnier of the Oak Ridge National Laboratory, who reviewed this report, are also appreciated.

FOREWORD

This compilation of occupational safety data for the uranium fuel cycle was initiated in the spring of 1979 under the auspices of the Technology Assessment Division of the Department of Energy's (DOE) Office of Environmental Assessment. The project was essentially completed in the fall of 1980, but the report was not published at that time pending the completion of peer review. During this time, N. M. Serrajian served as the DOE Project Manager. Environmental assessment projects previously assigned to the Office of Environmental Assessment are now assigned to Office of the Assistant Secretary for Environmental Protection, Safety and Emergency Preparedness.

In compiling the data reported herein, we used the best and most complete data available. However, persons who are familiar with this subject matter will realize that obtaining data from many sources presents numerous problems, including (1) significant differences in the formats used in presenting the data, (2) significant differences in the reporting criteria, and (3) inconsistencies between manpower and productivity data and injury data.

In addition, we were confronted with both the lack of data in certain critical areas and the requirement to normalize all available data. Missing data were approximated by using information from similar industries whose safety records were often not as good as those of the technology under consideration. This led to calculation of conservative occupational casualty coefficients. The complex question of data normalization is addressed at several points in the report and will not be discussed in this brief foreword.

This compilation is, of course, limited by the data that went into it. While no attempts were made to assign an overall accuracy to the data and coefficients reported herein, we conscientiously identified the sources of all data, with its limitations and its accuracy where reported. A case of particular concern is illustrated by a comparison of the data from the Mine Safety and Health Administration (MSHA) and the Bureau of Labor Statistics (BLS). The MSHA data include both injuries and illnesses, whereas injury and illness data are reported separately by the

BLS. Therefore, in order to make the MSHA and BLS information comparable, the injury and illness data from the latter were combined. This is but one example of many data-handling problems which were addressed and are noted herein.

Despite the inherent limitations of the available data, we believe that the thorough documentation of data sources and the self-consistent presentation of technology-specific data and casualty coefficients make this report a valuable source of data and information for persons wishing to assess technology-specific occupational risks.

SUMMARY

Evaluations of energy technologies and their incorporation into a rational energy policy are currently of great national interest and are being pursued actively by many organizations. One of the many factors considered in such policy evaluations is risk to the health of persons employed in the energy-related technologies. This report is intended to provide risk assessors and policy makers with self-consistent, comparable occupational casualty information on the technologies that make up the uranium fuel cycle. It contains several chapters, each covering a specific technology for preparing, processing, and/or using uranium. Technologies (and processes) included are uranium extraction (underground and open-pit mining), uranium milling, uranium conversion, uranium enrichment (gaseous diffusion and gas centrifugation), reactor fuel fabrication, generation of electricity (several reactor types*), transmission of electric power, and transportation of uranium and reactor fuel between the various technologies.

Each chapter briefly describes a technology and its constituent processes. Whenever possible, process-specific occupational casualty, manpower, and production data are given and are used to calculate sets of normalized occupational casualty incidence rates for each process or technology. In some cases, the requisite specific data were unavailable, thus necessitating use of more general data. Each section and chapter describes and documents sources of the data contained therein. Also documented fully are the procedures used to calculate the incidence rates from the data.

Tables S.1 through S.3 summarize some of the process-specific occupational casualty incidence rates that are given in this volume. Anyone desiring to use these rates is cautioned to read Appendix A, the example at the end of Chap. 1, and the sections of this report in which the rates are derived. Although we attempted to make the rates comparable with each

*Types of reactors included in the study: light-water reactor (LWR), high-temperature gas-cooled reactor (HTGR), liquid-metal fast breeder reactor (LMFBR), light-water breeder reactor (LWBR), and heavy-water reactor (HWR).

Table 8.1. Summary of fatality rates for operation and maintenance of technologies associated with production of electricity from uranium

Technology	Per 100 man-years		Per 10^{12} Btu output	
	Mean value	Standard deviation	Mean value	Standard deviation
Mining — underground	0.11	0.045	0.0011[a]	0.00082
— open pit	0.06[b]	c	0.0003[a,b]	c
Milling	0.013	0.025	0.000042[a]	0.000084
Conversion	0.014[b]	c	0.0000061[b,d]	c
Enrichment — gaseous diffusion	0.0023	0.0046	0.000027[d]	0.000054
— gas centrifugation	0.0023[b]	c	0.000059[b,d]	c
Fuel fabrication	0.0034[b]	c	0.000017[b,d]	c
Electric power production — LWR	0.01[b]	c	0.0006[b,d]	c
— HTGR	0.01[b]	c	0.0006[b,d]	c
— LMFBR	0.01[b]	c	0.0006[b,d]	c
— LWBR	0.01[b]	c	0.0006[b,d]	c
— HWR	0.01[b]	c	0.0006[b,d]	c
Electric power transmission	0.025	0.050	0.00058[a]	0.0012
Transportation:				
Mill to conversion — truck	0.061	c	0.00000024[a,b]	c
Conversion to enrichment — truck	0.061	c	0.00000012[a,b,e]	c
— rail	0.023	c	0.000000067[a,b,e]	c
Enrichment to fuel fabrication — truck	0.061	c	0.000000098[a,b]	c
Fuel fabrication to power plant — truck	0.061	c	0.000000078[a,b]	c

[a]Based on total energy content of actual output.

[b]Estimated value.

[c]Insufficient data to calculate this value.

[d]Based on total energy content of rated output (i.e., full utilization of installed capacity).

[e]Average of fatality rates for the various types of shipments given in Table 9.1.

Table S.2. Summary of serious-case incidence rates for operation and maintenance of technologies associated with production of electricity from uranium

Technology	Per 100 man-years		Per 10^{12} Btu output	
	Mean value	Standard deviation	Mean value	Standard deviation
Mining — underground	5.8	0.67	0.057[a]	0.015
— open pit	2.0	0.86	0.0095[a]	0.0062
Milling	1.8	0.55	0.[illegible][a]	0.0022
Conversion	2.4[b]	c	0.0010[b,d]	c
Enrichment — gaseous diffusion	0.13	0.083	0.0013[b]	0.000057
— gas centrifugation	0.13[b]	c	0.0034[b,d]	c
Fuel fabrication	0.55	c	0.0028[b,d]	c
Electric power production — LWR	0.78	0.54	0.049[b]	c
— HTGR	0.78[b]	c	0.043[b,d]	c
— LMFBR	0.78[b]	c	0.043[b,d]	c
— LWBR	0.78[b]	c	0.049[b,d]	c
— HWR	0.78[b]	c	0.043[b,d]	c
Electric power transmission	0.66	0.17	0.017[a]	0.0049
Transportation:				
Mill to conversion — truck	8.2	c	0.000032[a,b]	c
Conversion to enrichment — truck	8.2	c	0.000016[a,b,e]	c
— rail	4.7	c	0.000014[a,b,e]	c
Enrichment to fuel fabrication — truck	8.2	c	0.000013[a,b]	c
Fuel fabrication to power plant — truck	8.2	c	0.000010[a,b]	c

[a]Based on total energy content of actual output.

[b]Estimated value.

[c]Insufficient data to calculate this value.

[d]Based on total energy content of rated output (i.e., full utilization of installed capacity).

[e]Average of serious-case incidence rates for the various types of shipments given in Table 9.1.

Table S.3. Summary of lost-workday rates for operation and maintenance of technologies associated with production of electricity from uranium

Technology	Per 100 man-years		Per 10^{12} Btu output	
	Mean value	Standard deviation	Mean value	Standard deviation
Mining — underground	350	140	3.4[a]	1.3
— open pit	140	87	0.6[a]	0.47
Milling	48	13	0.6[a]	0.060
Conversion	21[b]	c	0.0092[b,d]	c
Enrichment — gaseous diffusion	25	6.9	0.29[d]	0.044
— gas centrifugation	25[b]	c	0.64[b,d]	c
Fuel fabrication	13[b]	c	0.065[b,d]	c
Electric power production — LWR	33	27	2.1[d]	c
— HTGR	33[b]	c	1.8[b,d]	c
— LMFBR	33[b]	c	1.8[b,d]	c
— LWBR	33[b]	c	2.1[b,d]	c
— HWR	33[b]	c	1.9[b,d]	c
Electric power transmission	99	20	2.5[a]	0.48
Transportation:				
Mill to conversion — truck	160	c	0.00062[a,b]	c
Conversion to enrichment — truck	160	c	0.00032[a,b,e]	c
— rail	83	c	0.00025[a,b,e]	c
Enrichment to fuel fabrication — truck	160	c	0.00026[a,b]	c
Fuel fabrication to power plant — truck	160	c	0.00020[a,b]	c

[a]Based on total energy content of actual output.

[b]Estimated value.

[c]Insufficient data to calculate this value.

[d]Based on total energy content of rated output (i.e., full utilization of installed capacity).

[e]Average of lost-workday rates for the various types of shipments given in Table 9.1.

other, this was not always possible. Some data upon which the rates are based (e.g., lost workdays) were collected and reported using incomparable definitions.

Table S.1 gives the mean number of fatalities per 100 man-years of labor and per trillion British thermal units (10^{12} Btu) of output for each technology and process considered in this volume. Mean values, unless identified as estimates, are the arithmetic means of several years' data. The standard deviations given are sample standard deviations over the several years considered.

Table S.2 gives mean numbers of "serious cases" per 100 man-years and per 10^{12} Btu and the associated sample standard deviations. As explained in Appendix A, the definition of a "serious case" depends on the system used to record the data. It may refer to nonfatal disabling injuries and illnesses or to lost-workday cases (injuries and illnesses) involving days away from work.

Table S.3 gives mean numbers of "lost workdays" per 100 man-years and per 10^{12} Btu and the associated sample standard deviations. As noted above, extreme care should be exercised when using lost-workday rates in risk comparisons. Very different definitions of "lost workdays" are used in different reporting systems.

The Btu's of output are the total energy content of the output (actual or rated) product for each process (e.g., the available energy in the ^{235}U in the ore mined, not necessarily the usable energy). Therefore, to use the rates given in Tables S.1 through S.3 in assessing a given energy production scenario, the rates for a given technology or process should be multiplied by the total amount of energy required by that technology or process for the production of energy. This procedure is illustrated at the end of Chapter 1.

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F. R. O'Donnell H. C. Hoy

ABSTRACT

Occupational casualty (injuries, illnesses, fatalities, and lost workdays) and production data are presented and used to calculate occupational casualty incidence rates for technologies that make up the uranium fuel cycle, including: mining, milling, conversion, and enrichment of uranium; fabrication of reactor fuel; transportation of uranium and fuel elements; generation of electric power; and transmission of electric power. Each technology is treated in a separate chapter. All data sources are referenced. All steps used to calculate normalized occupational casualty incidence rates from the data are presented. Rates given include fatalities, serious cases, and lost workdays per 100 man-years worked, per 10^{12} Btu of energy output, and per other appropriate units of output.

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1. INTRODUCTION

This report presents occupational casualty (injuries, illnesses, fatalities, and lost workdays) incidence rates for operation and maintenance of the technologies that make up the uranium fuel cycle (i.e., the cycle used in the production of electricity using uranium fuel). Table 1.1 lists the technologies and processes considered. They were selected to correspond to the nuclear fuel cycle technologies ("base units") discussed in *Environmental Data - Energy Technology Characterizations* (USDOE, 1980).

Each chapter of this report covers a specific technology (e.g., uranium mining). If a technology includes more than one process, its chapter is divided into sections — one for each process (e.g., the uranium mining chapter is divided into two sections: one covering underground mining, the other covering surface mining). Each chapter begins with a brief overview and description of the technology and processes covered. A table of occupational casualty incidence rates is presented and discussed for each process. This table lists the mean and, if available, the annual number of fatalities, serious cases, and lost workdays per 100 man-years,

Table 1.1. Technologies and processes in the uranium fuel cycle that are considered in this report

Uranium mining
Underground mines
Open-pit mines
Uranium milling
All mills
Uranium conversion
Uranium enrichment
Gaseous diffusion plants
Gas centrifuge plants
Fuel fabrication
Electric power generation
Light-water-reactor plants
Other nuclear plants
Electric power transmission
Transportation

per 10^{12} Btu of energy output, and per other appropriate units of output. Each incidence rate table is supported by a documented tabulation of the occupational casualty, manpower, and productivity data from which the incidence rates were calculated. For some processes, no actual data are available. In such cases, either of two approaches was used. First, if the process under consideration was similar to one for which data were available, the available data were used to calculate incidence rates for that process. In this case, the section lists and explains the derivation of the rates; it does not repeat the data (see Sect. 5.2). Second, if the process under consideration had no close counterpart for which data were available, data from a generically similar industry (e.g., the Standard Industrial Classification that includes the process) were presented and used to calculate the incidence rates (see Chaps. 4 and 9). In this case, the section contains both the rates and the data.

It is obvious from the preceding discussion that the quality of the data used in this report is quite variable. It follows that the quality of the occupational casualty incidence rates which are derived from the data will also be variable. To make clear our opinion of the quality of the rates, we have classified the rates given in each chapter as "self-contained," "synthesized," "derived," or "constructed."

1. "Self-contained" rates are those calculated from casualty, manpower, and production data obtained from one source.

2. "Synthesized" rates are those calculated by combining casualty and corresponding manpower data obtained from one source with production and corresponding manpower data obtained from another source.

3. "Derived" rates are those calculated by combining data obtained from multiple sources.

4. "Constructed" rates are those calculated from data obtained from similar or generically related processes (because no data exist on the process of interest).

Four points are important to the understanding and use of this document:

1. The incidence rates are based on data collected under more than one set of injury, illness, and lost-workday definitions. Consistency requires that data collected and reported under the different definitions be used in a manner which gives equivalent results. (Appendix A covers this topic in some detail.) Therefore, all data have been recast to correspond as much as possible to data collected under definitions promulgated by the Occupational Safety and Health Administration (OSHA).

2. The occupational casualty rates given in this report include all reported injuries and illnesses. Because the available casualty data on some technologies combine injuries and illnesses, consistency required that we combine all reported injuries and illnesses, even when reported separately. (In most cases, reported illnesses constitute only a few percent of the total.) Unfortunately, the reported illnesses include only those that manifest themselves during the reporting years; they do not include latent illnesses that afflict persons who have retired or changed occupations. Most latent illnesses are probably not counted in the conventional occupational casualty reporting systems.

3. Outputs are sometimes expressed in terms of actual output, sometimes in terms of output capability (rated output times 8760 h/year), and sometimes in terms of both. The choice of expression is dictated by the type of facility being considered and the available data. The annual output of a fixed-capacity plant (e.g., a single-unit, electric-power-generating plant) can vary widely because of scheduled or unscheduled outages, but the work force required at the plant might be unaffected. In such cases, incidence rates expressed in terms of total work force and output capability can give more meaningful and usable estimates than do rates expressed in terms of actual output. Variable-capacity plants (e.g., plants having several production lines) can vary both output and labor requirements and are well represented by rates given in terms of actual output. The discussion accompanying each process gives the safety definitions and the output bases used in establishing the incidence rates for that process. (This discussion also applies to input units.)

4. Outputs/inputs are expressed both in physical and in energy units. Each technology produces a physical product (e.g., mining produces a quantity of uranium ore, which is expressed in terms of its mass). This product might contain subproducts (e.g., uranium ore contains U_3O_8, which contains ^{235}U). The subproduct of interest contains a total amount of energy, which is expressed in terms of 10^{12} Btu (e.g., 1 ton of ^{235}U contains 70.8×10^{12} Btu, based on complete fission of ^{235}U. This total energy, which should not be confused with usable or recoverable energy, is the basic unit of energy output used in this report.

The occupational casualty incidence rates in this report can be used to estimate occupational casualties from the uranium fuel cycle's contribution to any energy production scenario. The procedure is straightforward. For example, suppose an energy production scenario requires, among other things, a supply of 10^6 tons of uranium ore from underground mines and the generation of 1 TWh of usable electric energy by light-water-reactor (LWR) nuclear power plants. We want an estimate of the number of occupational fatalities that might occur during uranium mining and electricity generation. This can be done as follows (note that the same procedures can be used to estimate numbers of serious cases and lost workdays).

For this scenario, as stated previously, 10^6 tons of uranium from an underground mine are required. From Table 2.2, we find a mean fatality rate of 0.97 fatalities/10^6 tons of ore. Therefore, we estimate that approximately one fatality will occur during the mining of 10^6 tons of ore (tons required times fatality per ton). We may also note that 10^6 tons of ore contain approximately 920×10^{12} Btu of total energy. Therefore, we may also multiply the fatalities per 10^{12} Btu (0.0011) given in Tables 2.2 and 5.1 by 920×10^{12} Btu to obtain the same result. This is an example of a direct calculation.

To estimate the number of deaths from generating enough electricity in LWR plants to supply 1.0 TWh of usable electricity, we must do the following:

1. Determine the actual plant output required to supply 1 TWh (3.4×10^{12} Btu) of usable electric energy. To do this, we divide the required energy by the efficiency of the delivery (transmission) system, which should be given in the scenario but which can be estimated as 98% from Table 8.2. If the scenario gives a 90% delivery efficiency, the LWR plants must generate 1.1 TWh (1 TWh/0.9) or 3.8×10^{12} Btu.

2. Determine the rated plant output that will supply the actual output. This is done by dividing the actual output by the plant capacity, or availability factor, which should be given in the scenario. If this factor is 75%, the rated plant output must be 1.5 TWh (1.1 TWh ÷ 0.75) or 5.1×10^{12} Btu. (If the scenario does not give this factor, we can use 57% — the ratio of terawatt-hours of actual output per 100 man-years to terawatt-hours of rated output per 100 man-years, as given in Table 7.1. In this case, it would be simpler to skip this step and use fatalities per terawatt-hours of actual output from Table 7.1 in the next step.)

3. Estimate the number of fatalities associated with operating and maintaining the required LWR plant capability. This is done simply by multiplying the needed 1.5 TWh (5.1×10^{12} Btu) of plant capability by the mean fatality rate, 0.002 fatality/TWh (rated) [0.0006 fatality/10^{12} Btu (rated)], given in Table 7.1. (Table 5.1 also gives the Btu-based fatality rate.) Therefore, much less than 1 (0.003) fatality is expected during production of 1 TWh of usable electric power.

Other technologies can be evaluated in a similar manner. No problems should be encountered if the scenario is reasonably complete and the derivation of the casualty incidence rates is understood. Therefore, we encourage potential users of this document to make sure they understand the derivation and the basis of the casualty rates. Appendix A explains the definitions upon which the data are based. These also must be understood. Finally, because abbreviations of units of measurement and other abbreviations can sometimes be confusing, those used in this report are listed in Appendix B.

2. URANIUM MINING

Uranium extraction activity has been dominated by open-pit and underground mining of ore deposits containing nominally 0.2% uranium oxide (U_3O_8). This dominance continues, but other sources of U_3O_8 are becoming significant contributors. Table 2.1 summarizes uranium extraction activity in the United States from 1969 through 1978, as measured by receipts at domestic mills and buying stations (USDOE, 1979*a*, pp. 20–21). Basically, the table shows that (1) uranium mining is increasing; (2) open-pit mining produces ~60% of the ore; underground mining, ~40%; (3) the average U_3O_8 content of mined ore is decreasing (that of open-pit-mined ore has fallen from 0.24 to 0.12%; that of underground-mined ore, from a high of 0.25 to 0.15%); and (4) miscellaneous sources are contributing a slightly increasing percentage of total U_3O_8 receipts at mills and buying stations, while underground- and open-pit-mined ore contributed nearly equal percentages during the last 3 years listed. Table 2.1 excludes consideration of U_3O_8 recovered from wet-process phosphoric acid and leach liquor from copper dumps. The former is expected to yield ~10^5 tons of U_3O_8 through the year 2000; the latter, about 2×10^4 tons (USDOE, 1979*a*, p. 7). Other estimates, summarized elsewhere (Ryan and Cotter, 1980, pp. 4–8), indicate an annual U_3O_8 recovery rate of 3×10^3 tons from phosphoric acid production.

This chapter gives occupational casualty and production data from underground and open-pit mining of uranium ore. These data are used to calculate sets of "synthesized" occupational casualty incidence rates. Each section and the notes appended to the data tables contained therein identify data sources and explain any operations used to transform raw data into the evaluated form presented.

The casualty data were obtained from the Mining Enforcement and Safety Administration* (MESA) of the U.S. Department of the Interior (1976, 1978*a*, 1978*b*, and 1978*c*). These publications summarize annual data reported to MESA by metal mines and mills under requirements of Section 13 of Public Law 89-577 (the Federal Metal and Nonmetallic Mine Safety Act).

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*The functions of MESA were taken over in 1977 by the Mine Safety and Health Administration (MSHA) of the U.S. Department of Labor.

Table 2.1. Summary of domestic uranium extraction activity, 1969–78[a]

Calendar year	Total receipts,[a] 10^3 tons			Percent[b] of ore from		Percent[b] U_3O_8 in ore from		Percent[b] of total U_3O_8 from		
	Mined ore	U_3O_8 in mined ore	U_3O_8 from other sources[c]	Open-pit mines	Underground mines	Open-pit mines	Underground mines	Open-pit mines	Underground mines	Other sources[c]
1969	5,904	12.3	0.3	37	63	0.24	0.19	41	56	3
1970	6,324	[illegible].8	0.3	44	56	0.21	0.20	45	52	2
1971	6,279	[illegible].9	0.2	52	48	0.21	0.20	53	45	2
1972	6,418	13.7	0.2	61	39	0.21	0.22	58	40	1
1973	6,537	13.6	0.2	70	30	0.19	0.25	62	36	1
1974	7,027	12.4	0.2	60	40	0.17	0.18	60	40	2
1975	7,0[illegible]7	12.0	0.3	60	40	0.16	0.19	54	43	2
1976	8,608	13.5	0.5	54	46	0.15	0.17	49	48	4
1977	10,325	15.9	0.8	54	46	0.14	0.18	46	50	5
1978	1[illegible],342	18.8	1.4	58	42	0.12	0.15	48	46	7

[a]Based on receipts at domestic mills and buying stations.

[b]Percentage total may differ from 100 because of rounding.

[c]Other sources include mine waters, heap leach, solution mining, and refining residues.

Source: U.S. Department of Energy, Grand Junction Office. 1979a. *Statistical Data of the Uranium Industry*. GJO-100(79). pp. 20–21.

Under this law, mines and mills employing an average of ten or more workers during the year are required to report, among other things, the average number of employees, actual man-hours worked, number of fatalities,* numbers of disabling and nondisabling injuries and illnesses, and the number of lost workdays. The casualty data are reported under American National Standards Institute (ANSI) definitions (see Appendix A). They include injuries and illnesses reported during the year; delayed (latent) illnesses (e.g., lung cancer) frequently are not included.

Thus, the casualty data cover all workers (production, supervisory, technical, and clerical) at uranium mines that reported to MESA during the year. The data are presented in modified MESA format and include annual numbers of man-years (man-hours divided by 2000 man-hours per man-year) worked, fatalities, nonfatal disabilities by class of disability, nondisabling casualties, total casualties, and lost workdays. (As noted in Appendix A, the modified MESA basis means that the reported number of lost workdays is the number of days chargeable under ANSI less 6000 man-days per fatality and permanent total disability.) Since the employment and casualty figures come from the same sources, we consider the casualty data to be well matched. (These data are also used by the Bureau of Labor Statistics in their annual reporting of occupational injuries and illnesses in the United States.) However, the data may be biased because all fatalities are presumably reported, whereas injury, illness, and employment data from small mines (which are believed to have higher casualty rates than large mines) are not. Therefore, using this data in our calculations could have overestimated fatality rates and underestimated the other casualty rates slightly.

The production data were obtained from the Grand Junction Office of the U.S. Department of Energy (USAEC, 1973 and 1974*a*; USERDA, 1975 and 1976*a*). These data summarize, among other things, annual reports from mill operators, mine inspectors (somewhat subjective), and mine operators (voluntary). Employment data are supplied largely by mine inspectors and some mine operators and may be incomplete. The output data (million tons

*All fatalities are required to be reported, regardless of the employment level at the affected site.

of ore and tons of U_3O_8) are based on receipts at mill and ore buying stations and therefore may not be actual mine production data. They could include mill receipts from ore stockpiles. Incomplete manpower data could inflate calculations of output per employee. Uncertainties in output data are expected to have a negligible impact on subsequent calculations.

2.1 Underground Mines

This section lists, and explains the derivation of, occupational casualty incidence rates for operation and maintenance of underground uranium mines in the United States. Table 2.2 lists the incidence rates, and Table 2.3 presents the selected casualty and production data from which the incidence rates were derived.

The annual casualty incidence rates for 1972 through 1975 given in Table 2.2 were calculated directly from the data contained in Table 2.3. We classify them as "synthesized" incidence rates. Fatalities, serious cases (nonfatal disabilities), and lost workdays per 100 man-years were calculated from reported casualty data. Annual output values (10^{12} Btu, 10^3 tons of U_3O_8, and 10^6 tons of ore) per 100 man-years were calculated from the production data. Incidence rates per unit of output were obtained by dividing the appropriate rate per 100 man-years by the appropriate output per 100 man-years. Mean values and sample standard deviations represent the 4-year average of the designated rate.

2.2 Surface Mines

Open-pit mines produce virtually all domestic, surface-mined uranium and are the only type of surface mine for which occupational casualty data and production data are available. Therefore, this section lists, and explains the derivation of, occupational casualty incidence rates only for operation and maintenance of open-pit uranium mines. Table 2.4 lists the incidence rates, and Table 2.5 presents the selected casualty and production data from which the incidence rates were derived.

The annual casualty incidence rates for 1972 through 1975 given in Table 2.4 were calculated directly from the data contained in Table 2.5.

Table 2.2 Casualty incidence rates for operation and maintenance of underground uranium mines

	Year				Mean	Standard deviation
	1972	1973	1974	1975		
Fatalities/100 MY	0.051	0.12	0.092	0.16	0.11	0.045
Serious cases/100 MY	6.7	6.0	5.3	5.3	5.8	0.67
Lost workdays/100 MY	250	550	250	340	350	140
10^{12} Btu[a] output/100 MY	120	140	110	68	110	30
Fatalities/10^{12} Btu	0.00043	0.00089	0.00087	0.0023	0.0011	0.00082
Serious cases/10^{12} Btu	0.057	0.043	0.050	0.079	0.057	0.015
Lost workdays/10^{12} Btu	2.1	3.9	2.4	4.9	3.4	1.3
10^3 tons of U_3O_8 output/100 MY	0.28	0.32	0.25	0.16	0.25	0.070
Fatalities/10^3 tons of U_3O_8	0.19	0.38	0.37	0.99	0.48	0.35
Serious cases/10^3 tons of U_3O_8	24	19	21	34	24	6.5
Lost workdays/10^3 tons of U_3O_8	910	1700	1000	2100	1400	570
10^6 tons of ore output/100 MY	0.13	0.13	0.14	0.084	0.12	0.024
Fatalities/10^6 tons of ore	0.41	0.95	0.67	1.9	0.97	0.63
Serious cases/10^6 tons of ore	54	46	39	63	50	10
Lost workdays/10^6 tons of ore	2000	4200	1800	4000	3000	1300

[a]The Btu values used in calculating incidence rates are based on total available energy content of ^{235}U mined.

Table 2.3. Selected casualty and production data for operation and maintenance of underground uranium mines in the United States[a]

	Year			
	1972	1973	1974	1975
Casualty data[b] (based on modified MESA definitions)[c]				
Man-years	1,951 (1)	1,624 (6)	2,177 (9)	3,185 (12)
Fatalities	1 (1)	2 (6)	2 (9)	5 (12)
Nonfatal disabilities	131 (1)	97 (6)	115 (9)	169 (12)
Permanent total	0 (1)	0 (6)	1 (9)	1 (12)
Permanent partial	1 (1)	6 (6)	6 (9)	8 (12)
Temporary total	130 (1)	91 (6)	108 (9)	160 (12)
Nondisabling cases	224 (2)	155 (6)	255 (9)	238 (12)
Total cases	357 (2)	255 (6)	372 (9)	413 (12)
Lost workdays	4,917 (1)	8,857 (6)	5,422 (9)	10,664 (12)
Production data (based on actual output)				
Man-years	2,021 (3)	1,537 (7)	2,058 (10)	3,340 (13)
Output				
10^{12} Btu	2,385 (5)	2,123 (5)	2,177 (5)	2,262 (5)
Tons of U_3O_8	5,588 (4)	4,974 (8)	5,100 (11)	5,300 (14)
10^6 tons of ore	2.530 (4)	1.993 (8)	2.811 (11)	2.810 (14)
Input				
10^{12} Btu	*d*	*d*	*d*	*d*
Tons of U_3O_8	*d*	*d*	*d*	*d*
10^6 tons of ore	*d*	*d*	*d*	*d*

[a]Numbers in parentheses refer to the explanatory notes given on the following pages.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

[d]No data.

Notes to Table 2.3

1. U.S. Department of the Interior, 1976, pp. 32–36, 47–49, and 52. The man-years listed under casualty data are the reported number of man-hours worked in 110 mines divided by 2000 man-hours per man-year plus an allocation of 159 man-years worked in offices. Casualty data pertain largely to injuries; very few, if any, occupational illnesses are reported. Lost workdays were calculated by multiplying the reported nonfatal disabling injury severity rate by the reported number of man-hours worked (in millions), then subtracting 6000 man-days for each reported permanent total disability.

2. Nondisabling injuries and illnesses were not reported in 1972. This value was estimated by multiplying the number of disabling cases during 1972 (132) by the 1973–75 average number of nondisabling cases per disabling case (1.7).

3. To put the casualty and production figures on the same basis, the man-years listed under production data were estimated by multiplying the average number of employees (2200) at 141 mines (USAEC, 1973, pp. 20 and 54) by the average number of man-years worked per employee (0.9188), as derived from the casualty manpower data (see note 1).

4. USAEC, 1973, p. 7.

5. The energy content of mine output, in British thermal units, was calculated as follows: 1 ton of natural uranium contains 0.00711 ton of ^{235}U; complete fission of 1 ton of ^{235}U yields 7.08×10^{13} Btu (U.S. Department of Health, Education, and Welfare, 1970, p. 18); therefore, 1 ton of U_3O_8 contains 4.27×10^{11} Btu. It follows that 4.27×10^{11} Btu/ton of U_3O_8 multiplied by the tons of U_3O_8 mined gives the British thermal units of output. Division by 10^{12} gives 10^{12} Btu of output.

6. U.S. Department of the Interior, 1978*a*, pp. 29–37, 53–55, and 65. Same as note 1, but for 87 mines and an allocation of 178 man-years worked in offices.

7. Same as note 3 with 2007 employees in 122 mines (USAEC, 1974*a*, pp. 22 and 56) and 0.7659 man-year per employee, as derived from the casualty manpower data (note 6).

8. USAEC, 1974*a*, p. 7.

Notes to Table 2.3 (continued)

9. U.S. Department of the Interior, 1978*b*, pp. 29–37, 53–55, and 65. Same as note 1, but for 102 mines and an allocation of 245 man-years worked in offices.

10. Same as note 3 with 2567 employees in 123 mines (USERDA, 1975, pp. 27 and 70) and 0.8016 man-year per employee, as derived from the casualty manpower data (note 9).

11. USERDA, 1975, p. 10.

12. U.S. Department of the Interior 1978*c*, pp. 29–37, 53–54, and 64. Same as note 1, but for 128 mines and an allocation of 287 man-years worked in offices.

13. Same as note 3 with 3753 employees in 121 mines (USERDA, 1976*a*, pp. 28 and 72) and 0.8902 man-year per employee, as derived from casualty manpower data (note 12).

14. USERDA, 1976*a*, p. 10.

Table 2.4. Casualty incidence rates for operation and maintenance of open-pit uranium mines

	Year				Mean	Standard deviation
	1972	1973	1974	1975		
Fatalities/100 MY	0	0	0	0	0.06[a]	[b]
Serious cases/100 MY	3.1	2.1	1.1	1.5	2.0	0.86
Lost workdays/100 MY	70	140	92	260	140	87
10^{12} Btu[c] output/100 MY	170	310	250	200	230	61
Fatalities/10^{12} Btu	0	0	0	0	0.0003[a]	[b]
Serious cases/10^{12} Btu	0.018	0.0069	0.0046	0.0079	0.0095	0.0062
Lost workdays/10^{12} Btu	0.41	0.41	0.37	1.4	0.65	0.47
10^3 tons of U_3O_8 output/100 MY	0.40	0.72	0.59	0.46	0.54	0.14
Fatalities/10^3 tons of U_3O_8	0	0	0	0	0.1[a]	[b]
Serious cases/10^3 tons U_3O_8	7.9	2.9	2.0	3.4	4.0	2.6
Lost workdays/10^3 tons U_3O_8	180	190	160	580	280	200
10^6 tons of ore output/100 MY	0.19	0.38	0.34	0.29	0.30	0.081
Fatalities/10^6 tons of ore	0	0	0	0	0.2[a]	[b]
Serious cases/10^6 tons of ore	16	5.6	3.4	5.3	7.7	5.9
Lost workdays/10^6 tons of ore	370	360	270	912	480	290

[a]Based on average fatality rate (1972–77) for strip mining of bituminous coal (see text).

[b]Standard deviation cannot be calculated because of insufficient data.

[c]The Btu values used in calculating incidence rates are based on the total available energy content of ^{235}U mined.

Table 2.5. Selected casualty and production data for operation and maintenance of open-pit uranium mines in the United States[a]

	Year			
	1972	1973	1974	1975
Casualty data[b] (based on modified MESA definitions)[c]				
Man-years	1636 (1)	1634 (6)	1486 (9)	1839 (12)
Fatalities	0 (1)	0 (6)	0 (9)	0 (12)
Nonfatal disabilities	51 (1)	34 (6)	17 (9)	28 (12)
Permanent total	0 (1)	0 (6)	0 (9)	0 (12)
Permanent partial	0 (1)	1 (6)	1 (9)	1 (12)
Temporary total	51 (1)	33 (6)	16 (9)	27 (12)
Nondisabling cases	28 (2)	10 (6)	19 (9)	6 (12)
Total cases	79 (2)	45 (6)	36 (9)	35 (12)
Lost workdays	1147 (1)	2199 (6)	1368 (9)	4853 (12)
Production data (based on actual output)				
Man-years	2044 (3)	1204 (7)	1244 (10)	1467 (13)
Output				
10^{12} Btu	3449 (5)	3677 (5)	3116 (5)	2860 (5)
Tons of U_3O_8	8079 (4)	8614 (8)	7300 (11)	6700 (14)
10^6 tons of ore	3.887 (4)	4.544 (8)	4.216 (11)	4.247 (14)
Input				
10^{12} Btu	*d*	*d*	*d*	*d*
Tons of U_3O_8	*d*	*d*	*d*	*d*
10^6 tons of ore	*d*	*d*	*d*	*d*

[a]Numbers in parentheses refer to the explanatory notes given on the following pages.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

[d]No data.

Notes to Table 2.5

1. U.S. Department of the Interior, 1976, pp. 32–36, 47–49, and 52. The man-years listed under casualty data are the reported number of man-hours worked in 20 mines divided by 2000 man-hours per man-year plus an allocation of 91 man-years worked in offices. Casualty data pertain largely to injuries; very few, if any, occupational illnesses are reported. Lost workdays were calculated by multiplying the reported nonfatal disabling injury severity rate by the reported number of man-hours worked (in millions), then subtracting 6000 man-days for each reported permanent total disability.

2. Nondisabling injuries and illnesses were not reported for 1972. This value was estimated by multiplying the number of disabling cases during 1972 (51) by the 1973–75 average number of nondisabling cases per disabling case (0.54).

3. To put the casualty and production figures on the same basis, the man-years listed under production data were estimated by multiplying the average number of employees (1521) at 37 mines (USAEC, 1973, pp. 20 and 54) by the average number of man-years worked per employee (1.344), as derived from the casualty manpower data (see note 1).

4. USAEC, 1973, p. 7.

5. The energy content of mine output, in British thermal units, was calculated as follows: 1 ton of U_3O_8 contains 0.848 ton of natural uranium; 1 ton of natural uranium contains 0.00711 ton of ^{235}U; complete fission of 1 ton of ^{235}U yields 7.08×10^{13} Btu (U.S. Department of Health, Education, and Welfare, 1970, p. 18); therefore, 1 ton of U_3O_8 contains 4.27×10^{11} Btu. It follows that 4.27×10^{11} Btu multiplied by the tons of U_3O_8 mined gives the British thermal units of output. Division by 10^{12} gives 10^{12} Btu of output.

6. U.S. Department of the Interior, 1978*a*, pp. 29–37, 53–55, and 65. Same as note 1, but for 32 mines and an allocation of 172 man-years worked in offices.

7. Same as note 3 with 1509 employees in 3 mines (USAEC, 1974*a*, pp. 22 and 56) and 0.7979 man-year per employee, as derived from the casualty manpower data (note 6).

Notes to Table 2.5 (continued)

8. USAEC, 1974*a*, p. 7.

9. U.S. Department of the Interior, 1978*b*, pp. 29–37, 53–55, and 65. Same as note 1, but for 23 mines and an allocation of 147 man-years worked in offices.

10. Same as note 3 with 1361 employees in 31 mines (USERDA, 1975, pp. 27 and 70) and 0.9140 man-year per employee, as derived from the casualty manpower data (note 9).

11. USERDA, 1975, p. 10.

12. U.S. Department of the Interior, 1978*c*, pp. 29–37, 53–54, and 64. Same as note 1, but for 32 mines and an allocation of 164 man-years worked in offices.

13. Same as note 3 with 1753 employees in 23 mines (USERDA, 1976*a*, pp. 28 and 72) and 0.8979 man-year per employee, as derived from the casualty manpower data (note 12).

14. USERDA, 1976*a*, p. 10.

We classify them as "synthesized" incidence rates. Fatalities, serious cases (nonfatal disabilities), and lost workdays per 100 man-years were calculated from reported casualty data. Annual output values (10^{12} Btu, 10^3 tons of U_3O_8, and 10^6 tons of ore) per 100 man-years were calculated from the production data. Incidence rates per unit of output were obtained by dividing the appropriate rate per 100 man-years by the appropriate output per 100 man-years.

Except for fatality rates, the mean values and sample standard deviations given in Table 2.4 represent the 4-year average of the designated rates. In the case of fatalities, since none were recorded during the time interval for which we have data, we assumed the mean rate per 100 man-years to equal the average fatality rate per 100 man-years for strip mining of bituminous coal. Therefore, the "constructed" mean fatality rate per 100 man-years (0.06) is the 1972–75 average rate for coal mining (U.S. Department of the Interior 1978*d*, p. 15, 1978*e*, p. 15, 1978*f*, p. 15, 1978*g*, p. 15; U. S. Department of Labor, 1978*a*, p. 15, and 1979*a*, p. 15).* The other mean fatality rates were obtained by dividing the mean rate per 100 man-years by the appropriate mean rates of output per 100 man-years.

*This rate also corresponds to the upper bound of the 95% confidence interval for zero fatalities over the 4 years (n = 66 units of 100 man-years each) considered. This calculation assumes a binomial distribution for the casualty data (Snedecor and Cochran, 1967, p. 6).

3. URANIUM MILLING

Milling involves the use of mechanical and chemical processes to extract uranium from its ores and to concentrate it in a semirefined product called yellowcake, which may contain as much as 95% U_3O_8 by weight (USNRC, 1979, Sect. 3). Yellowcake is the feed material for uranium hexafluoride (UF_6) conversion plants.

Historically, uranium milling and mining activities have been closely related. In fact, mills are usually located near the mines or other operations that produce mill-feed materials. This arrangement minimizes the transport of great quantities of ore or other mill feed, but it could adversely affect the extraction efficiency of the mills if the U_3O_8 content of the locally mined ore decreases. In recent years several mills for processing materials from solution mining, phosphoric acid, and heap leaching operations have begun operation and now account for ~7 to 10% of the 1979 milling capacity in the United States (USDOE, 1979*a*, p. 86). This could affect future casualty and production data for mills.

This chapter gives occupational casualty and production data for the operation and maintenance of domestic uranium mills. It also gives the occupational casualty incidence rates and explains how the data were used to calculate the rates. The data were obtained from the same sources and have the same limitations as the uranium mining data (see Chap. 2).

The annual casualty incidence rates for 1972–75 given in Table 3.1 were calculated directly from the casualty and production data contained in Table 3.2. We classify them as "synthesized" incidence rates. Fatalities, serious cases (nonfatal disabilities), and lost workdays per 100 man-years were calculated from reported casualty data. Annual output values (10^{12} Btu and 10^3 tons of U_3O_8) per 100 man-years were calculated from the production data. Incidence rates per unit of output were obtained by dividing the appropriate rate per 100 man-years by the appropriate output per 100 man-years. Mean values and sample standard deviations represent the 4-year average of the designated rate.

Table 3.1. Casualty incidence rates for operation and maintenance of uranium mills

	Year				Mean	Standard deviation
	1972	1973	1974	1975		
Fatalities/100 MY	0.050	0	0	0	0.013	0.025
Serious cases/100 MY	2.6	1.8	1.3	1.6	1.8	0.55
Lost workdays/100 MY	71	40	41	38	48	16
10^{12} Btu[a] output/100 MY	300	430	300	230	310	83
Fatalities/10^{12} Btu	0.00017	0	0	0	0.000042	0.000084
Serious cases/10^{12} Btu	0.0087	0.0042	0.0044	0.0072	0.0062	0.0022
Lost workdays/10^{12} Btu	0.24	0.094	0.14	0.17	0.16	0.060
10^3 tons of U_3O_8 output/100 MY	0.70	1.0	0.71	0.53	0.74	0.20
Fatalities/10^3 tons of U_3O_8	0.072	0	0	0	0.018	0.036
Serious cases/10^3 tons of U_3O_8	3.7	1.8	1.9	3.1	2.6	0.94
Lost workdays/10^3 tons of U_3O_8	100	40	59	72	68	26

[a]The Btu values used in calculating incidence rates are based on total energy content of the ^{235}U milled.

Table 3.2. Selected casualty and production data for operation and maintenance of uranium mills in the United States[a]

	Year			
	1972	1973	1974	1975
Casualty data[b] (based on modified MESA definitions)[c]				
Man-years	1,991 (1)	1,859 (5)	1,716 (7)	1,914 (9)
Fatalities	1 (1)	0 (5)	0 (7)	0 (9)
Nonfatal disabilities	52 (1)	33 (5)	23 (7)	31 (9)
Permanent total	0 (1)	0 (5)	0 (7)	0 (9)
Permanent partial	2 (1)	1 (5)	1 (7)	0 (9)
Temporary total	50 (1)	32 (5)	22 (7)	31 (9)
Nondisabling cases	85 (2)	58 (5)	35 (7)	42 (9)
Total cases	138 (2)	92 (5)	58 (7)	74 (9)
Lost wo kdays	1,415 (1)	742 (5)	711 (7)	732 (9)
Production data (based on actual output)				
Man-years	1,836 (3)	1,323 (6)	1,629 (8)	2,191 (10)
Output				
10^{12} Btu	5,508 (4)	5,650 (4)	4,921 (4)	4,952 (4)
Tons of U_3O_8	12,900 (3)	13,235 (6)	11,528 (8)	11,600 (10)
Input				
10^{12} Btu	5,898 (4)	5,966 (4)	5,311 (4)	5,293 (4)
Tons of U_3O_8	13,812 (3)	13,976 (6)	12,442 (8)	12,400 (10)

[a]Numbers in parentheses refer to the explanatory notes given on the following pages.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 3.2

1. U.S. Department of the Interior, 1976, pp. 34–36, 47–49, and 52. The man-years listed under casualty data are the reported number of man-hours worked in 19 mills divided by 2000 man-hours per man-year plus an allocation of 124 man-years worked in offices. Casualty data pertain largely to injuries; very few, if any, occupational illnesses are reported. Lost workdays were calculated by multiplying the reported nonfatal disabling injury severity rate by the reported number of man-hours worked (in millions), then subtracting 6000 man-days for each reported permanent total disability.

2. Nondisabling injuries were not reported for 1972. This value was estimated by multiplying the number of disabling cases during 1972 (53) by the 1973–75 average number of nondisabling cases per disabling case (1.6).

3. To put the casualty and production figures on the same basis, the man-years listed under production data were estimated by multiplying the average number of employees (1530) at 20 mills (USAEC, 1973, pp. 54 and 61) by the average number of man-years worked per employee (1.200), as derived from the casualty manpower data (see note 1).

4. The energy content of mill input and output, in British thermal units, was calculated as follows: 1 ton of natural uranium contains 0.00711 ton of ^{235}U; complete fission of 1 ton of ^{235}U yields 7.08×10^{13} Btu (U.S. Department of Health, Education, and Welfare, 1970, p. 18); therefore, 1 ton of U_3O_8 contains 4.27×10^{11} Btu. It follows that 4.27×10^{11} Btu per ton of U_3O_8 multiplied by the tons of U_3O_8 milled gives the British thermal units of input/output. Division by 10^{12} gives 10^{12} Btu of input/output.

5. U.S. Department of the Interior, 1978*a*, pp. 33–37, 53–5., and 65. Same as note 1, but for 27 mills and an allocation of 179 man-years worked in offices.

6. Same as note 3 with 1522 employees in 18 mills (USAEC, 1974*a*, pp. 56 and 63) and 0.8690 man-year per employee, as derived from the casualty manpower data (note 5).

Notes to Table 3.2 (continued)

7. U.S. Department of the Interior, 1978*b*, pp. 33–37, 53–55, and 65. Same as note 1, but for 20 mills and an allocation of 163 man-years worked in offices.

8. Same as note 3 with 1713 employees in 16 mills (USERDA, 1975, pp. 70 and 78) and 0.9511 man-year per employee, as derived from the casualty manpower data (note 7).

9. U.S. Department of Interior, 1978*c*, pp. 33–37, 53–54, and 64. Same as note 1, but for 19 mills and an allocation of 157 man-years worked in offices.

10. Same as note 3 with 2237 employees in 17 mills (15 conventional, 1 for solution-mined U_3O_8, and 1 for U_3O_8 recovered from phosphoric acid operations) (USERDA, 1976*a*, pp. 72, 80, and 82) and 0.9793 man-year worked per employee, as derived from the casualty manpower data (note 9).

4. FUEL CONVERSION

Uranium leaves the mills as uranium oxide (U_3O_8). This chemical form is incompatible with uranium enrichment processes, which require uranium hexafluoride (UF_6). Therefore, the U_3O_8 must be converted to UF_6. This is the function of a fuel conversion plant.

At present (1981), only two conversion plants are operating. Although the conversion processes used in each plant differ in detail, they are similar in that both are large-scale inorganic-chemical processes which use large quantities of hydrogen fluoride (HF) and handle large quantities of UF_6. Both plants use techniques and equipment similar to those used at other large chemical facilities. This commonality with other chemical plants was used to "construct" the occupational incidence rates for uranium fuel conversion that are given in Table 4.1.

Incidence rates for uranium fuel conversion were "constructed" as follows:

1. A partial set of data on occupational injuries and illnesses in fuel conversion plants was obtained (Baker, 1976) (Table 4.2). We could obtain no data from the operating plants.

2. A complete set of data was obtained (Inzana, 1980) on occupational injuries and illnesses in the industrial inorganic-chemical, not elsewhere classified, industry (U.S. Department of Labor, 1978*b* and 1979*b*) (Table 4.3).

3. The complete data set was used to fill in the partial set of data (Table 4.2). This was done by taking appropriate ratios within and between the data sets (see notes appended to Table 4.2). Such a procedure is valid because fuel conversion plants are classified as industrial inorganic-chemical, not elsewhere classified, facilities.

4. Design production capacity and nominal manpower requirements for the Sequoyah Uranium Hexafluoride Plant (USNRC, 1975) were used to calculate incidence rates per unit of output.

Table 4.1. Casualty incidence rates for operation and maintenance of uranium fuel conversion plants, based on 1973–74 data

	Value
Fatalities/100 MY	0.014
Serious cases/100 MY	2.4
Lost workdays/100 MY	21
10^{12} Btu[a] output/100 MY	2290
Fatalities/10^{12} Btu	0.0000061
Serious cases/10^{12} Btu	0.0010
Lost workdays/10^{12} Btu	0.0092
Tons of ^{235}U output[b]/100 MY	32
Fatalities per ton of ^{235}U	0.00044
Serious cases per ton of ^{235}U	0.075
Lost workdays per ton of ^{235}U	0.66
Tons of uranium processed[b]/100 MY	4550
Fatalities per ton of uranium	0.0000031
Serious cases per ton of uranium	0.00053
Lost workdays per ton of uranium	0.0046

[a]The British thermal unit values used in calculating incidence rates are based on the total energy content of the ^{235}U in the natural uranium.

[b]Based on rated plant capacity (see notes 2 and 3 of Table 4.3).

Table 4.2. Casualty and production data for operation and maintenance of uranium fuel conversion plants in the United States, based on 1973–74 data[a]

	Value
Casualty data[b] (based on OSHA definitions)[c]	
Man-years	100
Fatalities	0.014 (1)
Lost-workday cases	3.4 (2)
With days off	2.4 (3)
With restricted workdays	1.0 (3)
Lost workdays	21 (2)
Days off	15.0 (4)
Days of restricted work	6.0 (4)
Non-lost-workday cases	7.8 (2)
Total cases	11.2 (2)
Production data (based on design capacity of plants)	
Man-years	110 (5)
Output	
10^{12} Btu	2,520 (5)
Tons of ^{235}U	35.6 (5)
Tons of uranium	5,000 (5)

[a]Numbers in parentheses refer to the explanatory notes given on the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 4.2

1. Derived as follows: total lost-workday cases per 100 man-years from this table (3.4) divided by total lost-workday cases per 100 man-years from Table 4.3 (2.6) multiplied by the number of facalities per 100 man-years from Table 4.3 (0.011).

2. Baker, 1976.

3. Derived as follows: lost-workday cases with days off (or restricted workdays) per 100 man-years from Table 4.3 [1.8 (or 0.8)] divided by total lost-workday cases per 100 man-years from Table 4.3 (2.6) multiplied by total lost-workday cases per 100 man-years from this table (3.4).

4. Derived as follows: lost workdays with days off (or days of restricted work) per 100 man-years from Table 4.3 [39.0 (or 15.6)] divided by total lost workdays per 100 man-years from Table 4.3 (54.6) multiplied by total lost workdays per 100 man-years from this table (21).

5. USNRC, 1975. Information is based on a plant that employs 110 persons (≡110 man-years) to produce 4537 metric tons (5000 short tons) of uranium as UF_6 per year.

Outputs were calculated from the following: 1 metric ton of natural uranium contains 0.00711 metric ton of ^{235}U, and complete fission of 1 metric ton of ^{235}U yields 7.81×10^{13} Btu (U.S. Department of Health, Education, and Welfare, 1970, p. 18). Therefore, 4537 metric tons of natural uranium contains 32.3 metric tons of ^{235}U or 2.52×10^{15} Btu. In terms of short tons, 32.3 metric tons is equal to 35.6 short tons.

Table 4.3. Casualty and production data for operation and maintenance of industrial inorganic-chemical, not elsewhere classified, plants in the United States[a]

	Year							Mean of given values per 100 MY	Standard deviation
	1972	1973	1974	1975	1976	1977	1978		
				Casualty data[b] (based on OSHA definitions)[c]					
Man-years	95,690 (1)	98,393 (1)	101,245 (1)	104,510 (1)	105,252 (1)	104,806 (1)	107,169 (1)	1024	42
Fatalities	12 (2)	10 (1)	7 (2)	15 (1)	12 (2)	10 (1)		0.0108	0.0026
Lost-workday cases	2,715 (1)	2,675 (1)	3,140 (1)	2,690 (1)	2,610 (2)	2,440 (1)	2,335 (1)	2.60	0.31
With days off				1,795 (1)	1,840 (1)			1.79 (3)	0.40
With restricted workdays				895 (1)	770 (1)			0.83 (3)	0.24
Lost workdays				55,400 (1)	51,920 (1)			54.6 (4)	
Days off				40,975 (1)	36,585 (1)			39.0 (5)	17.3
Days of restricted work				14,425 (1)	15,335 (1)			15.6 (5)	9.4
Non-lost-workday cases	7,400 (1)	7,725 (1)	8,545 (1)	5,760 (1)	4,475 (1)	4,145 (1)	3,935 (1)	5.91	2.05
Total cases	10,127 (1)	10,410 (1)	11,692 (1)	8,465 (1)	7,097 (1)	6,595 (1)		8.97	2.22

[a]Numbers in parentheses refer to the explanatory notes given on the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 4.3

1. Inzana, 1980. More detailed data from U.S. Department of Labor, 1978*b* and 1979*b*.

2. Incomplete data on fatalities chargeable to illnesses indicated the number of such fatalities to be between one and four; we assumed it to be two.

3. Obtained by averaging the 1975–76 data to find the fractions of lost-workday cases that involve days off (0.687) and days of restricted work (0.314), and then multiplying by the mean number of lost-workday cases per 100 man-years.

4. Sum of days off plus days of restricted work per 100 man-years.

5. Obtained by averaging the 1975–76 data to find the average number of lost workdays per corresponding type of lost-workday case (21 days off per lost-workday case with days off, and 18 days of restricted work per lost-workday case with days of restricted work), and then multiplying by the mean number of lost-workday cases of that type per 100 man-years.

5. URANIUM ENRICHMENT

Light-water-moderated nuclear power reactors are fueled with enriched uranium (2–4% ^{235}U by weight). In the enrichment process, the ^{235}U content (0.71% by weight) of natural uranium is increased to the desired level. Only two enrichment processes, gaseous diffusion and gas centrifugation, are proven sufficiently for commercial application (USERDA, 1976*b*, pp. 2.1-35 to 2.1-51; USDOE, 1980, pp. 5-1 to 5-37). Both processes convert uranium hexafluoride (UF_6) into enriched UF_6 and a residue (tails) of depleted UF_6 (less than 0.71% ^{235}U by weight).

The gaseous diffusion process, since its large-scale implementation during World War II, has produced virtually all of the enriched uranium used in domestic nuclear power plants. The three operating gaseous diffusion plants are sources of good occupational casualty data and enriched-uranium production data. As of December 1979, these plants have a combined rated enrichment capacity of 17.2 MSWU/year (see note 3 to Table 5.2). Two programs to increase this rated enrichment capacity by ~10 MSWU/year are nearing completion (USDOE, 1979*b*, p. 3).

Gas centrifugation is in the development-and-demonstration stage. A demonstration plant that will contain a prototype, 0.023-MSWU/year gas centrifuge cascade is scheduled for completion late in 1982. After this facility is completed, a production-size gas centrifuge enrichment plant and an associated facility for manufacturing centrifuge rotors are to be built (USDOE, 1979*b*, pp. 3–4).

Section 5.1 gives occupational casualty, employment, and production data for operation and maintenance of gaseous diffusion plants for uranium enrichment. These data are used to calculate "self-contained" occupational casualty rates for the gaseous diffusion process (Sect. 5.1) and "constructed" occupational casualty rates for the gas centrifugation process (Sect. 5.2). Each section and the notes appended to the data tables contained therein identify data sources and explain any operations used to transform raw data into the evaluated form presented. Derivation of the casualty incidence rates from the data is also explained.

5.1 Gaseous Diffusion Plants

This section lists, and explains the derivation of, occupational casualty incidence rates for operation and maintenance of domestic gaseous diffusion plants for enriching uranium. Table 5.1 lists the incidence rates, and Table 5.2 presents the casualty, employment, and production data from which the rates were derived.

The casualty and employment (man-years) data in Table 5.2 were obtained from the gaseous diffusion plants (Sommerfield, 1980; Kaufner, 1979). Data are given only for the years 1975–78. These are the only years for which injury, illness, and lost-workday data were recorded under OSHA definitions (see Appendix A) by all three plants and were available to us.

The employment figures (man-years) given under both casualty and production data include all workers at the gaseous diffusion plant sites. These figures include a significant number of workers who are not engaged in gaseous diffusion operations (see note 1 of Table 5.2). We have not attempted to correct reported employment levels to account for the extraneous workers.* This is not expected to affect significantly the reported numbers of casualties and lost workdays (Sommerfeld, 1979), because most of the extraneous workers are employed in relatively casualty-free environs. However, the resulting casualty and output rates per 100 man-years (given in Table 5.1) could be low by a factor of ~1.5.† This would not affect the casualty rates per output, because, as explained later, employment effects cancel out during derivation of these rates.

Production data in Table 5.2 are based on the premise that gaseous diffusion plants are largely fixed-employment facilities (i.e., the

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*Because employment figures for other technologies very likely include employees who are not engaged in the operations of interest, we feel that selective correction of the gaseous diffusion plant data is not justified.

†Based on information given in note 1 of Table 5.2, ~33% of the reported man-years could be attributed to workers not involved in gaseous diffusion operations. Therefore, the total (reported) number of man-years could be 1.5 times the number of man-years expended in diffusion operations. [Total man-years/(1 − 0.33) total man-years = 1.5.]

Table 5.1. Casualty incidence rates for operation and maintenance of gaseous diffusion plants for uranium enrichment

	Year				Mean	Standard deviation
	1975	1976	1977	1978		
Fatalities/100 MY	0.0	0.0	0.0092	0.0	0.0023	0.0046
Serious cases/100 MY	0.26	0.12	0.092	0.074	0.13	0.083
Lost workdays/100 MY	31	30	19	19	25	6.9
10^{12} Btu[a] output/100 MY	120	98	86	86	97	16
Fatalities/10^{12} Btu	0.0	0.0	0.00011	0.0	0.000027	0.000054
Serious cases/10^{12} Btu	0.0021	0.0012	0.0011	0.00086	0.0013	0.00057
Lost workdays/10^{12} Btu	0.26	0.31	0.22	0.22	0.25	0.044
Tons of ^{235}U output[b]/100 MY	1.7	1.4	1.2	1.2	1.4	0.22
Fatalities per ton of ^{235}U	0.0	0.0	0.0076	0.0	0.0019	0.0038
Serious cases per ton of ^{235}U	0.15	0.084	0.076	0.061	0.093	0.041
Lost workdays per ton of ^{235}U	19	22	16	15	18	3.1
MSWU output[c]/100 MY	0.22	0.18	0.16	0.16	0.18	0.029
Fatalities/MSWU	0.0	0.0	0.058	0.0	0.015	0.029
Serious cases/MSWU	1.2	0.64	0.58	0.47	0.71	0.31
Lost workdays/MSWU	140	170	120	120	140	24

[a]The British thermal unit values used in calculating incidence rates are based on the total energy content of the ^{235}U in the enriched uranium product, based on rated enrichment capacity.

[b]Based on rated enrichment capacity (see notes 3 and 4 of Table 5.2).

[c]Based on rated enrichment capacity (see note 3 of Table 5.2).

Table 5.2. Casualty and production data for operation and maintenance of gaseous diffusion plants in the United States[a]

	Year			
	1975	1976	1977	1978
Casualty data[b] (based on OSHA definitions)[c]				
Man-years	7,825 (1)	9,604 (1)	10,910 (1)	10,847 (1)
Fatalities	0 (2)	0 (2)	1 (2)	0 (2)
Lost-workday cases	103 (2)	84 (2)	72 (2)	44 (2)
With days off	20 (2)	11 (2)	10 (2)	8 (2)
With restricted workdays	83 (2)	73 (2)	62 (2)	36 (2)
Lost workdays	2,443 (2)	2,894 (2)	2,057 (2)	2,020 (2)
Days off	880 (2)	1,131 (2)	636 (2)	1,081 (2)
Days of restricted work	1,563 (2)	1,763 (2)	1,421 (2)	939 (2)
Non-lost-workday cases	*d*	*d*	*d*	*d*
Total cases	*d*	*d*	*d*	*d*
Production data (based on design capacity of plants)				
Man-years	7.825 (1)	9,604 (1)	10,910 (1)	10,847 (1)
Output				
10^{12} Btu	9,350 (4)	9,350 (4)	9,350 (4)	9,350 (4)
Tons of ^{235}U	132 (4)	132 (4)	132 (4)	132 (4)
MSWU	17.2 (3)	17.2 (3)	17.2 (3)	17.2 (3)
Input				
10^{12} Btu	12,100 (4)	12,100 (4)	12,100 (4)	12,100 (4)
Tons of ^{235}U	171 (4)	171 (4)	171 (4)	171 (4)
MSWU	NA	NA	NA	NA

[a]Numbers in parentheses refer to the explanatory notes given on the following pages.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

[d]No data reported explicitly for this item.

Notes to Table 5.2

1. (Sommerfeld, 1980; Kaufner, 1979; Bailey, 1979. Employment data (obtained by private communication) are given for the three gaseous diffusion plants in terms of man-hours actually worked. Located at the site of the K-25 plant (Oak Ridge Gaseous Diffusion Plant) are certain operations not relevant to the gaseous diffusion process. Information gleaned from monthly and annual reports of the Finance and Budget Department of the Union Carbide Corporation, Nuclear Division (Sommerfeld, 1979) indicates that perhaps only 35 to 40% of the employees at the K-25 site are engaged in gaseous diffusion plant operations. We did not reduce the K-25 employment figures to account for this. If we assume that 37.5% of the reported K-25 employees are engaged in diffusion operations, the total employment figures would change to the following levels:

Year	Man-years	Percent of given value
1975	5229	66.8
1976	6233	64.9
1977	7208	66.1
1978	7175	66.1

2. (Sommerfeld, 1080; Kaufner, 1979. Both sources report man-hours worked, fatalities, lost-workday cases (LWDC), and lost workdays (LWD) under OSHA definitions. The LWDCs and LWDs for the Portsmouth Gaseous Diffusion Plant (Kaufner, 1979) are not separated into those involving days off and those involving days of restricted work. To do this, we multiplied the LWDCs and LWDs for Portsmouth by the 1975–78 average number (for the other plants) of LWDCs with days off per LWDC (0.15) and of LWDs with days off per LWD (0.38), respectively. The numbers of LWDCs and LWDs involving restricted-work days were obtained by subtraction. The resulting numbers of LWDCs and LWDs with days off and with days of restricted work were added to the numbers reported for the other plants. These total numbers are reported.

3. The enrichment capacity of the three gaseous diffusion plants is 17.2 million separative work units (MSWU) per year (USDOE, 1979b, p. 3).

Notes to Table 5.2 (continued)

We used rated enrichment capacity as the basic unit of output because (1) by U.S. Department of Energy directive, the Oak Ridge Gaseous Diffusion Plant reduces its electric power consumption, and thus its productivity, to ease demand on the electricity supply system, and (2) reductions in productivity at the diffusion plants are not necessarily accompanied by reductions in manpower. An SWU is a measure of the work required to produce uranium that is enriched to a specific level of ^{235}U from natural (or recycled) uranium while leaving uranium tailings that are depleted to a specific level of ^{235}U (USAEC, 1968, p. 7; USDOE, 1979*d*, p. 106). We use the following: 1 SWU (more properly 1 kg-SWU) is the work required to separate 1.272 kg (0.00140 ton) of natural uranium into 0.232 kg (0.000256 ton) of enriched uranium (containing 3% ^{235}U) plus 1.040 kg (0.00115 ton) of depleted uranium tailings (containing 0.2% ^{235}U). Thus, 17.2 MSWU will separate 24,080 tons of natural uranium into 4403 tons of enriched uranium plus 19,780 tons of depleted uranium.

4. From note 3 and from the fact that complete fission of 1 ton of ^{235}U yields 7.08×10^{13} Btu (U.S. Department of Health, Education, and Welfare, 1970, p. 18), we find that an input of 24,080 tons of natural uranium (0.711% ^{235}U) is equivalent to an input of 171.2 tons of ^{235}U (24,080 × 0.00711) or $12,100 \times 10^{12}$ Btu ($171.2 \times 7.08 \times 10^{13}$). Similarly, an output of 4403 tons of enriched uranium (3% ^{235}U) is equivalent to 132.1 tons of ^{235}U (4403 × 0.03) or 9350×10^{12} Btu ($132.1 \times 7.08 \times 10^{13}$). The 19,780 tons of depleted uranium tailings (0.2% ^{235}U) will contain 40.1 tons of ^{235}U (19,780 × 0.002) or 3800×10^{12} Btu ($40.1 \times 7.08 \times 10^{13}$).

number of employees depends on the rated output capacity of the plant and is not a sensitive function of actual plant output). Therefore, we report and use rated plant capacity as the basis for calculating casualty and output rates. (See note 3 of Table 5.2.) Using actual production data would give outputs per 100 man-years that are 0.75 times those given in Table 5.1.* This would give casualty rates per output that are 1.3 times (1/0.75) those given in Table 5.1.

Two programs to increase the capacity of the gaseous diffusion complex are nearing completion. They will add between 10.1 and 10.5 MSWU of capacity to the complex (USDOE 1979*b*, p. 3). The effects these programs will have on productivity, employment, and occupational casualties are unknown. Meanwhile, until data on the upgraded facilities become available, the use of the incidence rates given in Table 5.1 to estimate future occupational casualties in gaseous diffusion plants should give reasonably good results.

The annual occupational casualty incidence rates for 1975–78 given in Table 5.1 were calculated directly from the data in Table 5.2. We classify them as "self-contained" incidence rates. Fatalities, serious cases (lost-workday cases with days off), and lost workdays per 100 man-years were calculated from the reported casualty data. These agree reasonably well, where comparable, with rates reported by Baker (1976). Annual outputs (10^{12} Btu, tons of ^{235}U, and MSWU) per 100 man-years were calculated from the production data. Incidence rates per unit of output were obtained by dividing the appropriate rate per 100 man-years by the appropriate output per 100 man-years. Mean values and sample standard deviations represent the 4-year average of the designated rate.

5.2 Gas Centrifuge Plants

Occupational injury and illness, production capacity, and employment data for gas centrifuge plants are nonexistent. Rather than omit

*During 1975–78, the rated capacity of the plants was 17.2 MSWU, which we assume produced uranium enriched to 3% ^{235}U and uranium tailings depleted to 0.2% ^{235}U. Actual production during 1975–78 averaged ~12.9 MSWU (USERDA, 1977, p. 13; USDOE, 1978*a*, p. 12, and 1979*a*, p. 12). Therefore, actual production averaged ~75% of rated capacity.

consideration of this imminent technology, we "constructed" the casualty incidence rates given in Table 5.3 as follows:

1. The operation and maintenance work force per unit output will be larger in a gas centrifuge plant than in a gaseous diffusion plant (USDOE, 1979*b*, p. 8). Based on model plant designs (USERDA, 1976*b*, pp. 2.2-4 to 2.2-17), a gas centrifuge plant will employ ~286 persons per MSWU of capacity; an associated rotor manufacturing plant will employ 120 persons per MSWU of gas centrifuge plant capacity; and a gaseous diffusion plant will employ ~160 persons per MSWU. Thus, the number of employees per MSWU at a centrifuge plant could be ~1.8 times higher than that at a gaseous diffusion plant, or 2.5 times higher at a combined centrifuge and rotor fabrication plant. We adopted the combined plant value and reduced, by a factor of 2.5, the outputs per 100 man-years in Table 5.1 to give those in Table 5.3.

2. We assumed that the occupational injury and illness rates for the combined centrifuge and rotor fabrication plant will be equivalent to those for gaseous diffusion plants. Thus, the casualty rates per 100 man-years given in Table 5.1 were assumed to apply directly to the combined plant and are repeated in Table 5.3.

3. The casualty rates per unit of output in Table 5.3 were obtained by dividing the casualty rates per 100 man-years by the appropriate outputs per 100 man-years. (Because of the uncertainties involved, only a single set of casualty rates — equivalent to the mean values in Table 5.1 — is given. No attempt was made to define a standard deviation.)

Table 5.3. Casualty incidence rates for operation and maintenance of a combined gas centrifuge and rotor fabrication plant

	Value
Fatalities/100 MY	0.0023
Serious cases/100 MY	0.13
Lost workdays/100 MY	25
10^{12} Btu[a] output/100 MY	39
Fatalities/10^{12} Btu	0.000059
Serious cases/10^{12} Btu	0.0034
Lost workdays/10^{12} Btu	0.64
Tons of ^{235}U output[b]/100 MY	0.55
Fatalities per ton of ^{235}U	0.0042
Serious cases per ton of ^{235}U	0.24
Lost workdays per ton of ^{235}U	45
MSWU output[b]/100 MY	0.072
Fatalities/MSWU	0.032
Serious cases/MSWU	1.9
Lost workdays/MSWU	350

[a]The British thermal unit values used in calculating incidence rates are based on the total energy content of the ^{235}U in the enriched uranium product, based on rated enrichment capacity.

[b]Output is based on rated enrichment capacity.

6. FUEL FABRICATION

The basic function of a fuel fabrication plant is to fabricate uranium fuel assemblies for use in commercial power reactors. Most of the existing plants prepare assemblies with low-enriched (≤ 5 wt % ^{235}U) uranium for use in light-water reactors. The principal operations carried out at a fuel fabrication plant include: (1) conversion of enriched uranium hexafluoride (UF_6) to uranium dioxide (UO_2) powder; (2) fabrication of the UO_2 powder into pellets; (3) encapsulation of the pellets into fuel rods; (4) fabrication of the fuel rods into fuel assemblies; and (5) shipment of completed fuel assemblies to reactor sites.

Fabrication of fuel assemblies requires both chemical and mechanical operations. Conversion of UF_6 to UO_2 powder is a chemical process involving vaporization of the UF_6, which generates hydrogen, hydrogen fluoride, and nitrogen gases and steam. Pellet fabrication involves preparation of a homogenized mixture of UO_2 and appropriate additives; compaction, granularization, and pressing the mixture into pellets; and sintering the pellets in a reducing atmosphere. Encapsulation of the fuel rods involves grinding the pellets to specified dimensions, loading the ground pellets into metal tubes, and welding plugs to the metal tubes. Fuel assembly fabrication involves loading fuel rods into designated positions in a prefabricated support structure and attaching top closure. Completed fuel assemblies are inspected and loaded into approved shipping containers.

"Constructed" occupational casualty incidence rates for fuel fabrication plants are given in Table 6.1. These rates were derived by the same procedures used to estimate rates for fuel conversion plants (Sect. 4). Partial data from Baker (1976) were completed (Table 6.2) using data on the industrial inorganic-chemical industry (Table 4.3). Rated production capacity and nominal manpower requirements for an existing (USNRC, 1977) and a proposed (Westinghouse Electric Corporation, 1979) fuel fabrication plant were used to calculate incidence rates per unit of output.

Table 6.1. Casualty incidence rates for operation and maintenance of uranium fuel fabrication plants, based on 1973–74 data

	Value
Fatalities/100 MY	0.0034
Serious cases/100 MY	0.55
Lost workdays/100 MY	13
10^{12} Btu[a] output/100 MY	200
Fatalities/10^{12} Btu	0.000017
Serious cases/10^{12} Btu	0.0028
Lost workdays/10^{12} Btu	0.065
Tons of ^{235}U output[b]/100 MY	2.8
Fatalities per ton of ^{235}U	0.0012
Serious cases per ton of ^{235}U	0.20
Lost workdays per ton of ^{235}U	4.6
Tons of enriched uranium processed[b]/100 MY	93
Fatalities per ton of enriched uranium	0.000037
Serious cases per ton of enriched uranium	0.0059
Lost workdays per ton of enriched uranium	0.14

[a]The British thermal unit values used in calculating incidence rates are based on the total energy content of the ^{235}U in the 3% enriched uranium.

[b]Based on rated plant capacities (see note 5 of Table 6.2).

Table 6.2. Casualty and production data for operation and maintenance of uranium fuel fabrication plants in the United States, based on 1973–74 data[a]

	Value
Casualty data[b] (based on OSHA definitions)[c]	
Man-years	100
Fatalities	0.0034 (1)
Lost-workday cases	0.8 (2)
With days off	0.55 (3)
With restricted workdays	0.25 (3)
Lost workdays	12.8 (2)
Days off	9.1 (4)
Days of restricted work	3.7 (4)
Non-lost-workday cases	4.3 (2)
Total cases	5.1 (2)
Production data (based on design capacity of plants)	
Man-years	3550 (5)
Output	
10^{12} Btu	7030 (5)
Tons of ^{235}U	99 (5)
Tons of enriched uranium	3310 (5)

[a]Numbers in parentheses refer to the explanatory notes given on the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 6.2

1. Derived as follows: total lost-workday cases per 100 man-years from this table (0.8) divided by total lost-workday cases per 100 man-years from Table 4.3 (2.6) multiplied by the number of fatalities per 100 man-years from Table 4.3 (0.011).

2. Baker, 1976.

3. Derived as follows: lost-workday cases with days off (or restricted workdays) per 100 man-years from Table 4.3 [1.8 (or 0.8)] divided by total lost-workday cases per 100 man-years from Table 4.3 (2.6) multiplied by total lost-workday cases per 100 man-years from this table (0.8).

4. Derived as follows: lost workdays with days off (or days of restricted work) per 100 man-years from Table 4.3 [39.0 (or 15.6)] divided by total lost workdays per 100 man-years from Table 4.3 (54.6) multiplied by total lost workdays per 100 man-years from this table (12.8).

5. An existing plant has a rated capacity of 400 metric tons of enriched uranium per year and employs 700 persons, and a proposed capacity of 1600 metric tons with 1850 employees (USNRC, 1977). A proposed plant will have a capacity of 1000 metric tons per year and will employ 1000 persons. Combining these values gives a total capacity of 3000 metric tons (3308 tons) per year and 3550 employees (≡3550 man-years). A metric ton of enriched uranium (3 wt % ^{235}U) will contain 0.03 metric ton (0.033 ton) of ^{235}U. Therefore, the total output of ^{235}U is 90 metric tons (99 tons). Since complete fission of one metric ton of ^{235}U yields 7.81×10^{13} Btu of energy, 90 metric tons will yield 7.030×10^{15} Btu.

7. ELECTRIC POWER GENERATION

Nuclear power plants typically produce between 10 and 15% of the electric energy produced in the United States. For example, during 1977, 47 plants containing 63 reactor units generated 250.9 TWh of electricity, or 11.8% of the 2124 TWh produced in the United States (U.S. Department of Energy 1978*d*, pp. VII–XIV and 184–98). These plants had a combined installed capacity of 49,129 MW(e) with individual plant capacities averaging ~970 MW(e) and ranging between 65.3 and 3465 MW(e). The generating capacity of these plants was 430.4 TWh [49,129 MW(e) × 8760 h/year]. Therefore, the amount of electricity usually generated by the plants was ~60% of their potential generating capacity.

Through 1977, all operating nuclear power plants were equipped with light-water reactors (LWRs), including both pressurized- and boiling-water designs. A few high-temperature gas-cooled reactor units (HTGRs) are being readied for use. Other potentially important reactor designs are liquid-metal fast breeder reactors (LMFBRs), light-water breeder reactors (LWBRs), and heavy-water reactors (HWRs).

This chapter gives occupational casualty and production data for operation and maintenance of nuclear-fueled electric-power-generating plants. These data are used to calculate sets of "synthesized" occupational casualty incidence rates for LWRs (see Sect. 7.1). Rates for the other reactor types are "constructed" in Sect. 7.2 from the LWR occupational casualty data and engineering estimates of employment and production for each type of reactor. All occupational casualty data are based on OSHA definitions (see Appendix A).

7.1 Light-Water Reactors

This section lists, and explains the derivation of, occupational casualty incidence rates for operation and maintenance of domestic nuclear power plants equipped with light-water-moderated reactors. Table 7.1 lists the incidence rates, and Table 7.2 presents the selected casualty and production data from which the incidence rates were derived.

The casualty data in Table 7.2 were obtained from annual reports of the Tennessee Valley Authority (TVA) (Day, 1979). These reports list the

Table 7.1. Casualty incidence rates for operation and maintenance of light-water-reactor nuclear power plants

	Year			Mean	Standard deviation
	1975	1976	1977		
Fatalities/100 MY	0.0	0.0	0.0	0.01[a]	b
Serious cases/100 MY	0.38	0.27	1.7	0.78	0.80
Lost workdays/100 MY	13	23	64	33	27
10^{12} Btu rated[c] output/100 MY	16	16	15	16	0.58
Fatalities/10^{12} Btu (rated)	0.0	0.0	0.0	0.0006[a]	b
Serious cases/10^{12} Btu (rated)	0.023	0.017	0.11	0.050	0.052
Lost workdays/10^{12} Btu (rated)	0.82	1.4	4.4	2.2	1.9
TWh rated output/100 MY	4.8	4.7	4.3	4.6	0.26
Fatalities/TWh (rated)	0.0	0.0	0.0	0.002[a]	b
Serious cases/TWh (rated)	0.080	0.057	0.39	0.18	0.19
Lost workdays/TWh (rated)	2.8	4.9	15	7.6	6.5
10^{12} Btu actual[d] output/100 MY	9.3	8.9	8.7	9.0	0.31
Fatalities/10^{12} Btu (actual)	0.00	0.0	0.0	0.001[a]	b
Serious cases/10^{12} Btu (actual)	0.041	0.030	0.19	0.087	0.089
Lost workdays/10^{12} Btu (actual)	1.4	2.6	7.4	3.8	3.2
TWh actual output/100 MY	2.7	2.6	2.5	2.6	0.10
Fatalities/TWh (actual)	0.0	0.0	0.0	0.004[a]	b
Serious cases/TWh (actual)	0.14	0.10	0.65	0.30	0.31
Lost workdays/TWh (actual)	4.9	8.7	25	13	11

[a]Based on assumed value of 0.01 fatality/100 MY (see text).

[b]Standard deviation cannot be calculated because of insufficient data.

[c]Based on rated generating capacity times 8760 h.

[d]Based on electricity actually generated.

Table 7.2. Selected casualty and production data for operation and maintenance of light-water-reactor nuclear power plants in the United States[a]

	Year		
	1975	1976	1977
Casualty data[b] (based on OSHA definitions)[c]			
Man-years	523 (1)	754 (1)	787 (1)
Fatalities	0 (1)	0 (1)	0 (1)
Lost-workday cases	5 (1)	7 (1)	21 (1)
With days off	2 (1)	2 (1)	13 (1)
With restricted workdays	3 (1)	5 (1)	8 (1)
Lost workdays	70 (1)	171 (1)	505 (1)
Days off	55 (1)	124 (1)	402 (1)
Days of restricted work	15 (1)	47 (1)	103 (1)
Non-lost-workday cases	68 (1)	81 (1)	77 (1)
Total cases	73 (1)	88 (1)	98 (1)
Production data (based on rated capacity and actual output of plants)			
Man-years	5113 (2)	6307 (4)	7210 (5)
Output			
10^{12} Btu (rated)	838 (3)	1004 (3)	1047 (3)
10^{12} Btu (actual)	477 (3)	560 (3)	625 (3)
TWh (rated)	246 (2)	294 (4)	307 (5)
TWh (actual)	140 (2)	164 (4)	183 (5)
Input			
10^{12} Btu	*d*	*d*	*d*

[a]Numbers in parentheses refer to the explanatory notes given on the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

[d]No data reported explicitly for this entry.

Notes to Table 7.2

1. Day, 1979. Occupational injury and illness data and matching manpower data taken from TVA annual reports.

2. U.S. Department of Energy, 1978*b*, pp. 177–86. An annual summary of performance data on all nuclear power plants. We selected and summed the number of employees, the net electric power generation, and the rated electric-power-generating capability (rated capacity times 8760 h) for plants that operated normally during the year (i.e., those that brought no new units into service nor had any abnormal maintenance requirements). These are 1975 data and include reports based on a calendar year and reports based on a fiscal year (July 1, 1974–June 30, 1975).

3. This value is based on rated electric-power-generating capability. It is obtained as follows: 1 kWh = 3412 Btu; therefore, 1 TWh = 10^9 kWh = 3.412×10^{12} Btu.

4. U.S. Department of Energy 1978*c*, pp. 183–95. Same as note 2, but for 1976.

5. U.S. Department of Energy 1978*d*, pp. 184–98. Same as note 2, but for 1977.

annual numbers of fatalities, lost-workday cases, non-lost-workday cases, lost workdays, and man-hours worked at TVA's nuclear power plants; OSHA definitions are used (see Appendix A). The data cover all employees involved in reactor startup, testing, operation, and maintenance.

Production data were obtained for each domestic nuclear power plant that was licensed to operate during the indicated year (U.S. Department of Energy, 1978*b*, pp. 177–86; 1978*c*, pp. 183–95; and 1978*d*, pp. 184–98). The data listed in Table 7.2 cover only those plants that operated normally during the year (i.e., those that did not add new units nor experience long, unscheduled shutdowns). By summing the contribution of each covered plant, we obtained the annual number of employees (which we equate with the number of man-years worked), actual quantities of electricity generated, and the rated generating capabilities (installed generating capacities multipled by 8760 h).

The annual casualty incidence rates for 1975 through 1977 given in Table 7.1 were calculated directly from the data contained in Table 7.2. We classify them as "synthesized" incidence rates, with the reservations noted in the following paragraphs. Fatalities, serious cases (lost-workday cases with days off), and lost workdays per 100 man-years were calculated from the casualty data. Annual rated values and actual output values (10^{12} Btu and TWh) per 100 man-years were calculated from the production data. Incidence rates per unit of output were obtained by dividing the appropriate rate per 100 man-years by the appropriate output per 100 man-years.

Except for the fatality rates, the mean values and sample standard deviations given in Table 7.1 represent the 3-year average of the designated rate. In the case of fatalities, since none were recorded during the time interval considered, the mean values are rates based on an assumed rate of 0.01 fatality per 100 man-years.* (We believe that this

*This fatality rate is comparable to other estimates (see Table 7.3). Also, it corresponds to ~7% of the upper bound of the 95% confidence interval (0 to 0.15 fatalities per 100 man-years) for 0 fatalities over 3 years (n = 20.64 units of 100 man-years). If preliminary data for 1978 and 1979 (Day, 1979) are added to those in Table 7.2, the chosen rate corresponds to ~15% of the upper bound (0 to 0.07 fatalities per 100 man-years) for 0 fatalities over 5 years (n = 50.52 units of 100 man-years). These calculations assume a binomial distribution for the casualty data (Snedecor and Cochran, 1967, p. 6).

rate is an overestimate, perhaps by a factor 10.) The remaining mean fatality rates were obtained by dividing fatalities per 100 man-years by the appropriate mean rate of output per 100 man-years.

Caution is urged in using the casualty incidence rates in Table 7.1. Although the casualty data are reliable and specific to nuclear power plant operation and maintenance, they are from a sample that is small and not necessarily representative of the industry. Therefore, the combination of limited casualty data and complete production data could produce casualty incidence rates that deviate significantly from a true industry average. This, however, does not appear to be a problem, because the incidence rates in Table 7.1 are in reasonable agreement with rates derived by other investigators. For comparison, Table 7.3 presents casualty rates that were calculated from two independent data sources together with rates based on TVA data.

Bertolett and Fox (1974) obtained operation and maintenance casualty data, under ANSI definitions, for 1969–72 from six electric utilities, five of which operated nuclear plants. These data are widely used in risk assessments. We have cast these data into an OSHA-compatible format for inclusion in Table 7.3. Bertolett and Fox also reported, without citation, other published casualty data; these are also given in Table 7.3. Hub et al. (1973, pp. II-182 to II-184) give values that were constructed from data collected by the U.S. Department of Labor (1968 and 1969). These data are aggregates of casualty data collected under ANSI definitions from a variety of nuclear and support facilities. The aggregated data were manipulated by Hub et al. to produce casualty rates per million man-hours, which we converted to rates per 100 man-years. [We made all values of lost workdays per terawatt-hour of actual output compatible, but not comparable, with OSHA definitions by subtracting the days attributable to fatalities (6000 days per fatality multiplied by the given fatality rate) from the reported values.]

We chose to use the rates derived from TVA data because they are well documented, are in the OSHA format, and offer good prospects for continued accumulation. Also, the TVA data are based on a slightly greater number of man-hours worked than are the data from Bertolett and Fox. Finally, the incidence rates calculated from the TVA data (and those from Bertolett

Table 7.3. Occupational casualty incidence rates from several sources for operation and maintenance of light-water-reactor nuclear power plants

	TVA[a]	Bertolett and Fox[b]		Hub et al.[c]
		From their survey	Other cited values	
Fatalities/100 MY	0.01[d]	0.0	0.006	0.0080
Serious cases/100 MY	0.78	0.56	0.76	1.0
Lost workdays/100 MY	33	13	29	32
TWh actual output[e]/100 MY	2.6	3.9	3.9	5.0
Fatalities/TWh (actual)	0.004	0.0	0.02	0.0016
Serious cases/TWh (actual)	0.30	0.14	0.20	0.20
Lost workdays/TWh (actual)	13	3.3	7.5	6.4

[a]From Table 7.1; values based on OSHA definitions.

[b]Bertolett and Fox, 1974. Values are based on ANSI definitions. Original values have been put into units corresponding to OSHA definitions.

[c]Hub et al., 1973, pp. II-182 to II-184. Values are based on ANSI definitions. Original values have been put into units corresponding to OSHA definitions.

[d]Estimated value.

[e]Terawatt-hours actually generated.

and Fox) are based only on nuclear power plant data; they are not calculated from aggregated data on a variety of facilities, as are the rates of Hub et al.

7.2 Other Types of Nuclear Reactors

Occupational injury and illness data do not exist for reactor types other than LWRs. However, there is a need for at least "ballpark" estimates of occupational casualty incidence rates for the other types of reactors. Therefore, we "constructed" such incidence rates from the LWR casualty rates per 100 man-years and from engineering estimates of manpower requirements to operate and maintain the other reactor types. Table 7.4 gives theoretical outputs per 100 man-years and "constructed" casualty incidence rates for HTGRs, LMFBRs, LWBRs, and HWRs.

To construct Table 7.4, we assumed that all types of nuclear power plants would have the same number of casualties per 100 man-years as do LWRs. Differences between plant types were assumed to affect only productivity (TWh and 10^{12} Btu rates output per 100 man-years). We used an engineering estimate (Myers, 1979, pp. 19–26) of manpower requirements for typically sized reactors of the desired types to calculate the productivity values given in Table 7.4. Manpower requirements include all on-site (operation, supervisory, and security) and off-site (peak maintenance) personnel normally associated with power plant operation and maintenance. The incidence rates in Table 7.4 were obtained by dividing incidence rates per 100 man-years (from Table 7.1) by terawatt-hours rated output per 100 man-years and 10^{12} Btu rated output per 100 man-years. [The productivity values in Table 7.1, 4.5 TWh rated output per 100 man-years for an LWR, are in good agreement with those in the engineering study, 4.9 TWh rated output per 100 man-years for a boiling-water reactor (BWR) and 4.6 TWh rated output per 100 man-years for a pressurized-water reactor (PWR).]

Table 7.4. Estimated occupational casualty incidence rates for operation and maintenance of nuclear power plants equipped with various types of reactors

	LWR[a]	HTGR[b]	LMFBR[b]	LWBR[b]	HWR[b]
Fatalities/100 MY	0.01				
Serious cases/100 MY	0.78				
Lost workdays/100 MY	33				
10^{12} Btu rated output[c]/100 MY	16	18[d]	18[d]	16[e]	17[d]
Fatalities/10^{12} Btu	0.0006	0.0006	0.0006	0.0006	0.0006
Serious cases/10^{12} Btu	0.049	0.043	0.043	0.049	0.046
Lost workdays/10^{12} Btu	2.1	1.8	1.8	2.1	1.9
TWh rated output[f]/100 MY	4.6	5.4[d]	5.4[d]	4.6[e]	4.9[d]
Fatalities/TWh	0.002	0.002	0.002	0.002	0.002
Serious cases/TWh	0.17	0.14	0.14	0.17	0.16
Lost workdays/TWh	7.2	6.1	6.1	7.2	6.7

[a]From Table 7.1. Values may differ slightly due to different averaging scheme.

[b]Assumes values per 100 MY are the same for all reactor types.

[c]Based on rated generating capacity.

[d]Myers, 1979, pp. 19–26.

[e]Assumes LWBR and LWR are equivalent.

[f]Terawatt-hours of rated generating capacity (installed capacity times 8760 h).

8. ELECTRIC POWER TRANSMISSION

Electric power is transmitted throughout the nation via a complex, interconnected system of overhead, underground, and submarine power lines. These lines are shared by electric-power-generating plants and therefore cannot be assigned in general to a specific plant or type of plant.

Each electric-power-generating company and power-distributing organization maintains a part of the total system. This system includes transmission and distribution lines that have power ratings from a few kilovolts to 850 kV, a variety of line and substation transformers, meters, and substations.

This chapter gives selected occupational casualty and production data for operation and maintenance of very high voltage (350 kV and higher) transmission lines. These data are used to calculate sets of "synthesized" occupational casualty incidence rates. Table 8.1 lists the incidence rates, and Table 8.2 presents the data.

The casualty data in Table 8.2 were obtained from information given in TVA annual reports (Day, 1979). These reports list the annual numbers of fatalities, lost-workday cases, non-lost-workday cases, lost workdays, and man-hours worked in connection with operation and maintenance of TVA's power distribution network; OSHA definitions are used (see Appendix A).

Production data include the manpower figures from the casualty data. They also include the annual quantity of electric energy transmitted across TVA's power distribution network and the circuit-miles of transmission line that make up the network (Federal Power Commission, 1975, pp. 10FP and 10FPA; USDOE, 1978*e*, p. 414C-FP; 1979*e*, p. 154; and 1979*f*, p. 158).

The annual occupational casualty incidence rates for 1975 through 1978 given in Table 8.1 are classified as "synthesized." Fatalities, serious cases (lost-workday cases with days off), and lost workdays per 100 man-years were calculated directly from the casualty data. Annual output values (10^{12} Btu and TWh transmitted, and 10^3 circuit-miles) per 100 man-years were calculated from the production data. Incidence rates per unit of output were obtained by dividing the appropriate casualty rate

Table 8.1. Casualty incidence rates for operation and maintenance of very high voltage electric power transmission lines

	Year				Mean	Standard deviation
	1975	1976	1977	1978		
Fatalities/100 MY	0.0	0.0	0.0	0.10	0.025	0.050
Serious cases/100 MY	0.58	0.88	0.49	0.70	0.66	0.17
Lost workdays/100 MY	88	110	77	120	99	20
10^{12} Btu transmitted[a]/100 MY	37	38	44	43	41	3.5
Fatalities/10^{12} Btu	0.0	0.0	0.0	0.0023	0.00058	0.0012
Serious cases/10^{12} Btu	0.016	0.023	0.011	0.016	0.017	0.0049
Lost workdays/10^{12} Btu	2.4	2.9	1.8	2.7	2.5	0.48
TWh transmitted[b]/100 MY	11	11	13	13	12	1.2
Fatalities/TWh	0.0	0.0	0.0	0.0079	0.0020	0.0040
Serious cases/TWh	0.053	0.078	0.038	0.055	0.056	0.017
Lost workdays/TWh	8.1	9.9	6.0	9.4	8.4	1.7
10^3 circuit-miles[c]/100 MY	1.6	1.7	1.6	1.7	1.7	0.058
Fatalities/10^3 circuit-miles	0.0	0.0	0.0	0.059	0.015	0.030
Serious cases/10^3 circuit-miles	0.36	0.53	0.30	0.42	0.40	0.098
Lost workdays/10^3 circuit-miles	55	67	47	71	60	11

[a]Based on energy content of electricity transmitted through system.

[b]Electric power transmitted through system.

[c]Circuit-miles of transmission line that make up the system.

Table 8.2. Selected casualty and production data for operation and maintenance of very high voltage electric power transmission lines in the United States[a]

	Year			
	1975	1976	1977	1978
Casualty data[b] (based on OSHA definitions)[c]				
Man-years	1,039 (1)	1,021 (1)	1,026 (1)	997 (1)
Fatalities	0 (1)	0 (1)	0 (1)	1 (1)
Lost-workday cases	15 (1)	24 (1)	24 (1)	13 (1)
With days off	6 (1)	9 (1)	5 (1)	7 (1)
With restricted workdays	9 (1)	15 (1)	19 (1)	6 (1)
Lost workdays	915 (1)	1,142 (1)	785 (1)	1,190 (1)
Days off	150 (1)	306 (1)	350 (1)	362 (1)
Days of restricted work	765 (1)	836 (1)	435 (1)	828 (1)
Non-lost-workday cases	49 (1)	76 (1)	53 (1)	37 (1)
Total cases	64 (1)	100 (1)	77 (1)	51 (1)
Production data (based on actual output)				
Man-years	1,039 (1)	1,021 (1)	1,026 (1)	997 (1)
Output				
10^{12} Btu	385 (3)	393 (3)	447 (3)	443 (3)
TWh	113 (2)	115 (4)	131 (5)	127 (6)
Circuit-miles	16,762 (2)	16,937 (4)	16,861 (5)	16,858 (6)
Input				
10^{12} Btu	395 (3)	404 (3)	459 (3)	445 (3)
TWh	116 (2)	118 (4)	134 (5)	130 (6)

[a]Numbers in parentheses refer to the set of explanatory notes given in the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 8.2

1. Day, 1979. Data used in Tennessee Valley Authority (TVA) annual reports were obtained by private communication from B. C. Day of TVA at Chattanooga, Tennessee.

2. Federal Power Commission, 1975, pp. 10FP and 10FPA. Total circuit-miles of electric power transmission lines maintained by TVA are given. Input values represent total electric power that entered the TVA power distribution system (net generation plus purchased electricity plus electric power interchanged). Output values represent the amount of electric power delivered from the system (input less power losses and internal utility uses).

3. The British thermal unit values are obtained by multiplying terawatt-hours of input and output by 3.412×10^{12} Btu/TWh.

4. USDOE, 1978*e*, p. 414C-FP. See note 2.

5. USDOE, 1979*e*, p. 154. See note 2.

6. USDOE, 1979*f*, p. 158. See note 2.

per 100 man-years by the appropriate output per 100 man-years. Mean values and sample standard deviations represent the 4-year average of the designated rates.

To our knowledge, Table 8.2 contains the only available set of casualty and production data specifically on operation and maintenance of electric power transmission lines. Thus, even though the size of the sample is small (~7% of the electric power generated in the United States during 1977 passed through TVA's transmission lines), the data and the incidence rates calculated therefrom are valuable for assessments of electric power transmission systems.

9. TRANSPORTATION

Transportation links the various technologies in the uranium fuel cycle. The overall transportation scheme is complicated by the various shipping distances involved and by the various load sizes and types of packaging used. Basically, the transportation modes considered in this report involve the movement of uranium ore from mines to mills; U_3O_8 from mills to conversion plants; natural UF_6 from conversion plants and importers to enrichment plants; enriched UF_6 between enrichment plants, from enrichment plants to fuel fabrication plants and exporters, and from fuel fabrication plants to reactor sites. Truck and rail are the dominant modes of transportation.

Before occupational casualty incidence rates could be calculated, it was necessary to define a representative transportation scheme for the uranium fuel. To do this, we evaluated several documented schemes (USAEC, 1974*b*; Hub et al., 1973; and Gefen et al., 1978) and adopted the scheme that is summarized in Table 9.1. Shipment descriptions were taken directly from the references. Average shipping distances were either taken directly from the references or, for UF_6 shipments, were calculated by taking actual shipping distances between plants, multiplying them by the fraction of the total annual mass of UF_6 shipped over each distance, and summing the results of the multiplications. The energy content per shipment was obtained by multiplying the mass (in pounds) of ^{235}U per shipment by the energy available from complete fission of that mass of ^{235}U (viz., 3.54×10^{10} Btu/lb of ^{235}U) (U.S. Department of Health, Education, and Welfare, 1970).

Occupational casualty incidence rates for transport of uranium and reactor fuel (Table 9.2) were then "constructed," using the appropriate incidence rates per 100 man-years and per million vehicle/car-miles for all trucking and rail transport in the United States (Table 9.3). The incidence rates for trucking were "constructed" from the data in Table 9.4; those for rail transport, from the data in Table 9.5.

Care should be exercised when using the incidence rates given in Table 9.2, because they were derived using unmatched data. The casualty

Table 9.1. Summary of transportation schemes for the uranium fuel cycle

Shipment to:	Material shipped	Mode of shipment	Description	Average distance per shipment (miles)	Gross weight per shipment [tons (metric tons)]	Weight of ^{235}U per shipment (lb)	Energy content per shipment (10^{12} Btu)	Source
Conversion plants	U_3O_8 (natural)	Truck	40 55-gal drums	800	17.6 (16.0)	199	7.07	1, 2
Enrichment plants	UF_6 (natural)	Truck	1 14-ton cylinder	280	16.4 (14.9)	133	4.69	3
	UF_6 (natural)	Truck	2 10-ton cylinders	690	25.5 (23.2)	202	7.16	3
	UF_6 (natural)	Rail	4 14-ton cylinders	520	65.5 (59.4)	530	18.8	3
	UF_6 (0.96% ^{235}U)	Rail	4 14-ton cylinders	330	65.5 (59.4)	716	25.4	3
	UF_6 (3% ^{235}U)	Truck	1 10-ton cylinder with overpack	260	18.0 (16.3)	427	15.1	3
Fuel fabrication plants and exporters	UF_6 (3% ^{235}U)	Truck	3 2.5-ton cylinders with overpack	830	20.3 (18.5)	306	17.8	3
Reactors	UO_2 (3% ^{235}U)	Truck	6 steel boxes	425	26.9 (24.4)	325	11.5	1, 2

Sources: 1. USAEC, 1974b.
2. Hub et al., 1973.
3. Geffen et al., 1978.

Table 9.2. Casualty incidence rates (constructed) for transport of uranium and reactor fuel in the United States

Shipments to:	Material shipped	Mode of shipment	Coefficient	Number per: Shipment	Ton of ^{235}U	10^{12} Btu
Conversion plants	U_3O_8 (natural) in 55-gal drums	Truck	Fatalities	1.7×10^{-6}	1.7×10^{-5}	2.4×10^{-7}
			Serious cases	2.2×10^{-4}	2.3×10^{-3}	3.2×10^{-5}
			Lost workdays	4.4×10^{-3}	4.4×10^{-2}	6.2×10^{-4}
Enrichment plants	UF_6 (natural) in 14-ton cylinders	Truck	Fatalities	5.9×10^{-7}	8.8×10^{-6}	1.3×10^{-7}
			Serious cases	7.8×10^{-5}	1.2×10^{-3}	1.7×10^{-5}
			Lost workdays	1.5×10^{-3}	2.3×10^{-2}	3.3×10^{-4}
	UF_6 (natural) in 10-ton cylinders	Truck	Fatalities	1.4×10^{-6}	1.4×10^{-5}	2.0×10^{-7}
			Serious cases	1.9×10^{-4}	1.9×10^{-3}	2.7×10^{-5}
			Lost workdays	3.8×10^{-3}	3.8×10^{-2}	5.3×10^{-4}
	UF_6 (natural) in 14-ton cylinders	Rail	Fatalities	1.7×10^{-6}	6.5×10^{-6}	9.1×10^{-8}
			Serious cases	3.5×10^{-4}	1.3×10^{-3}	1.9×10^{-5}
			Lost workdays	6.2×10^{-3}	2.4×10^{-2}	3.3×10^{-4}
	UF_6 (0.96% ^{235}U) in 14-ton cylinders	Rail	Fatalities	1.1×10^{-6}	3.0×10^{-6}	4.3×10^{-8}
			Serious cases	2.2×10^{-4}	6.2×10^{-4}	8.7×10^{-6}
			Lost workdays	4.0×10^{-3}	1.1×10^{-2}	1.6×10^{-4}
	UF_6 (3% ^{235}U) in 10-ton cylinders with overpack	Truck	Fatalities	5.5×10^{-7}	2.6×10^{-6}	3.6×10^{-8}
			Serious cases	7.3×10^{-5}	3.4×10^{-4}	4.8×10^{-6}
			Lost workdays	1.4×10^{-3}	6.7×10^{-3}	9.5×10^{-5}
Fuel fabrication plants and exporters	UF_6 (3% ^{235}U) in 2.5-ton cylinders with overpack	Truck	Fatalities	1.7×10^{-6}	6.9×10^{-6}	9.8×10^{-8}
			Serious cases	2.3×10^{-4}	9.2×10^{-4}	1.3×10^{-5}
			Lost workdays	4.6×10^{-3}	1.8×10^{-2}	2.6×10^{-4}
Reactors	UO_2 (3% ^{235}U) in assemblies in steel boxes	Truck	Fatalities	8.9×10^{-7}	5.5×10^{-6}	7.8×10^{-8}
			Serious cases	1.2×10^{-4}	7.3×10^{-4}	1.0×10^{-5}
			Lost workdays	2.3×10^{-3}	1.4×10^{-2}	2.0×10^{-4}

Table 9.3. Casualty incidence rates for trucking and rail transport in the United States

	Truck	Rail
Fatalities/100 MY	0.061	0.023
Serious cases/100 MY	8.2	4.7
Lost workdays/100 MY	160	83
10^6 vehicle/car-miles/100 MY	29	7.0
Fatalities/10^6 vehicle/car-miles	0.0021	0.0033
Serious cases/10^6 vehicle/car-miles	0.28	0.67
Lost workdays/10^6 vehicle/car-miles	5.5	12
10^6 ton-miles/100 MY	110	190
Fatalities/10^6 ton-miles	0.00055	0.00012
Serious cases/10^6 ton-miles	0.075	0.025
Lost workdays/10^6 ton-miles	1.5	0.44

Table 9.4. Casualty and production data for trucking (local and long distance) in the United States[a]

	Year							Mean of given values per 100 MY	Standard deviation
	1972	1973	1974	1975	1976	1977	1978		
Casualty data[b] (based on OSHA definitions)[c]									
Man-years	979,425 (1)	1,054,243 (1)	1,074,047 (1)	962,330 (1)	1,003,038 (1)	1,092,460 (1)	1,151,961 (1)	10,454	677
Fatalities	595 (1)	625 (1)	610 (1)	560 (1)	380 (1)	1030 (1)		0.061	0.018
Lost-workday cases	71,580 (1)	84,315 (1)	91,880 (1)	72,960 (1)	81,445 (1)	92,175 (1)	109,535 (1)	8.2	0.72
With days off				72,035 (1)	80,570 (1)			8.2 (2)	0.72
With restricted workdays				925	875			0.03 (3)	0.01
Lost workdays				1,395,550	1,609,225			162 (4)	
Days off				1,383,185 (1)	1,573,780 (1)			158 (5)	23
Days of restricted work				12,365 (1)	35,445 (1)			3.8 (5)	5.
Non-lost-workday cases	89,625 (1)	95,635 (1)	99,955 (1)	68,345 (1)	70,585 (1)	69,690 (1)	77,305 (1)	7.8	1.3
Total cases	161,800	180,575	192,445	141,865	152,410	162,895		16.1	1.3
Production data (based on design capacity of plants)									
Man-years				1,054,6.0 (6)	973,032 (7)	1,112,989 (7)		10,469	703
Class I intercity				433,144 (6)	429,306 (7)	507,025 (7)		4,565	438
Output									
10^6 vehicle-miles (total)				274,454 (6)	307,950 (7)	329,465 (7)		29.1	2.8
10^6 ton-miles (class I intercity				454,000 (6)	510,000 (7)	555,000 (7)		111	7

[a]Numbers in parentheses refer to the explanatory notes given on the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 9.4

1. Inzana, 1980.

2. Assumed to be approximately equal to all lost-workday cases for 100 man-years, as indicated by the 1975–76 data.

3. Mean of 1975–76 data.

4. Sum of days off plus days of restricted work per 100 man-years.

5. Obtained by averaging the 1975–76 data to find the average number of lost workdays per corresponding type of lost-workday case (19 days off per lost-workday case with days off, and 107 days of restricted work per lost-workday case with restricted workdays), and then multiplying by the mean number of lost-workday cases of that type per 100 man-years.

6. U.S. Department of Transportation, 1978. Values are given for total employment in the trucking industry and for total vehicle-miles traveled, and for class I, intercity trucking employment, and class I, intercity ton-miles. Reported numbers of employees have been converted to man-years worked, using the ratio of man-years worked per employee from note 1.

7. U.S. Department of Transportation, 1979. Same as note 6.

Table 9.5. Casualty and production data for railroad transportation in the United States[a]

	Year						Mean of given values per 100 MY	Standard deviation
	1973	1974	1975	1976	1977	1978		
Casualty data[b] (based on OSHA definitions)[c]								
Man-years	538,239 (1)	565,095 (1)	499,906 (1)	501,840 (1)	523,790 (1)	509,643 (1)	5,231	252
Fatalities	170 (1)	145 (1)	105 (1)	90 (1)	107 (2)		0.023	0.005
Lost-workday cases	16,805 (1)	22,035 (1)	24,410 (1)	28,655 (1)	34,570 (1)	38,945 (1)	5.3	1.7
With days off			21,715 (1)	25,715 (1)			4.7 (3)	2.2
With restricted workdays			2,695	2,940			0.58 (3)	0.30
Lost workdays			391,320	395,485			83 (4)	
Days off			366,780 (1)	365,110 (1)			77 (5)	61
Days of restricted work			24,540 (1)	30,375 (1)			5.9 (5)	4.8
Non-lost-workday cases	29,415 (1)	25,370 (1)	18,015 (1)	22,200 (1)	22,150 (1)	22,110 (1)	4.4	0.6
Total cases	46,390	47,550	42,530	50,945	56,827		9.3	1.1
Production data (based on design capacity of plants)								
Man-years			416,384 (6)	391,109 (7)	430,358 (7)		4,126	199
Output								
10^6 cars and locomotives			1.346 (6)	1.299 (7)	1.263 (7)		0.000318	0.000021
10^6 car-miles			28,241 (6)	29,135 (7)	29,348 (7)		7.02	0.38
10^6 train-miles			437.4 (6)	459.4 (7)	459.7 (7)		0.110	0.007
10^6 ton-miles			754,252 (6)	794,059 (7)	826,292 (7)		192	11

[a]Numbers in parentheses refer to the explanatory notes given on the following page.

[b]Includes both injuries and illnesses.

[c]See Appendix A.

Notes to Table 9.5

1. Inzana, 1980.

2. Incomplete data on fatalities chargeable to illnesses indicated the number of such fatalities to be between one and four; we assumed it to be two.

3. Obtained by averaging the 1975–76 data to find the fractions of lost-workday cases that involve days off (0.893) and days of restricted work (0.107), and then multiplying by the mean number of lost-workday cases per 100 man-years.

4. Sum of days off plus days of restricted work per 100 man-years.

5. Obtained by averaging the 1975–76 data to find the average number of lost workdays per corresponding type of lost-workday case (16 days off per lost-workday case with days off, and 8 days of restricted work per lost-workday case with days of restricted work), and then multiplying by the mean number of lost-workday cases of that type per 100 man-years.

6. U.S. Department of Transportation, 1978. All values are for class I railroads. Reported numbers of employees have been converted to man-years worked, using the ratio of man-years worked per employee from note 1.

7. U.S. Department of Transportation, 1979. Same as note 6.

and production data used to derive the incidence rates apply to all trucking activities in the United States, including warehousing (Table 9.4), and to all rail transport (Table 9.5). Communications with trucking firms that actually transport radioactive materials indicated that, because of selective assignment of drivers with outstanding safety records and route planning, their safety record for shipments of radioactive materials was far better than their record for shipments of commercial goods. The safety record for rail shipments of radioactive materials may also be better than rail shipments of commercial goods, but this is unverified. The net effect of better safety records for transport of radioactive materials would be to reduce, probably significantly, the incidence rates given in Table 9.2.

REFERENCES

Acoin, P., Nuclear Assurance Corp., Fuel-Trac, Atlanta, Ga. 1980. Personal communication.

American National Standards Institute, Inc. 1969. *American National Standard Method of Recording Basic Facts Relating to the Nature and Occurrence of Work Injuries.* ANSI Standard Z.16.2-1962 (R1969).

American National Standards Institute, Inc. 1973. *American National Standard Method of Recording and Measuring Work Injury Experience.* ANSI Standard Z16.1-1967 (R1973).

Bailey, B. I. V., Oak Ridge Gaseous Diffusion Plant. 1979. Private communication.

Baker, K. R. 1976. The Safety of Workers in the Nuclear Fuel and Reactor Industries. *Nucl. Saf.* 17(3): 363–370.

Bertolett, A. D., and Fox, R. J. 1974. Accident-Rate Sample Favors Nuclear. *Electr. World* 182(2): 40–41.

Cuthbert, H., Oak Ridge Gaseous Diffusion Plant. 1979. Personal communication.

Day, B. C., Tennessee Valley Authority. 1979. Private communication.

Federal Power Commission. 1975. *Statistics of Publicly Owned Electric Utilities in the United States — 1975.*

Gefen, C. A.; Johnson, J. F.; Davis, D. H.; Friley, J. R.; and Ross, B. A. 1978. *An Assessment of the Risk of Transporting Uranium Hexafluoride by Truck and Train.* PNL-2211.

Hub, K. A.; Asbury, J. G.; Buehring, W. A.; Gast, P. F.; Schleuker, R. A.; Weills, J. T.; DuBois, K. P.; and Gardner, J. L. 1973. *Social Costs for Alternate Means of Electrical Power Generation for 1980 and 1990.* ANL-8093 (Vol. 2). Argonnne National Laboratory.

Inzana, C., U.S. Department of Labor. 1980. Personal communication.

Kaufner, A., U.S. Department of Energy. 1979. Private communication.

Myers, M. L. 1979. *Guidelines for Estimating Nonfuel Operation and Maintenance Costs for Alternative Nuclear Power Plants.* ORNL/TM-6860. Oak Ridge National Laboratory.

National Safety Council. 1979. *Work Injury and Illness Rates.*

Ryan, M. T., and Cotter, S. J. 1980. *An Integrated Assessment of the Phosphate Industry.* ORNL-5583 and ORNL/EV/OTI-2001. Oak Ridge National Laboratory.

Snedecor, G. W., and Cochran, W. G. 1967. *Statistical Methods*. 6th ed. The Iowa State University Press, Ames, Iowa.

Sommerfeld, K. W., Oak Ridge Gaseous Diffusion Plant. 1979. Private communication.

Sommerfeld, K. W., Oak Ridge Gaseous Diffusion Plant. 1980. Letter to H. C. Hoy, Oak Ridge National Laboratory, giving annual injury and illness data for two gaseous plants as reported to the National Safety Council.

U.S. Atomic Energy Commission. 1968. *AEC Gaseous Diffusion Plant Operations*. ORO-658.

U.S. Atomic Energy Commission. 1972. *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants*. Unnumbered.

U.S. Atomic Energy Commission, Grand Junction, Colo. 1973. *Statistical Data of the Uranium Industry*. GJO-100(73).

U.S. Atomic Energy Commission, Grand Junction, Colo. 1974*a*. *Statistical Data of the Uranium Industry*. GJO-100(74).

U.S. Atomic Energy Commission. 1974*b*. *Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy*, Appendix A: Energy Expenditures Associated with Electric Power Production by Nuclear and Fossil Fueled Power Plants. WASH-1224-A.

U.S. Department of Energy. 1978*a*. *Uranium Enrichment Services Activity, Financial Statements for Period Ended September 30, 1977*. ORO-759.

U.S. Department of Energy. 1978*b*. *Steam-Electric Plant Construction Cost and Annual Production Expenses 1975*. DOE/EIA-0033/1.

U.S. Department of Energy. 1978*c*. *Steam-Electric Plant Construction Cost and Annual Production Expenses 1976*.

U.S. Department of Energy. 1978*d*. *Steam-Electric Plant Construction Cost and Annual Production Expenses 1977*. DOE/EIA-0033/3(77).

U.S. Department of Energy. 1978*e*. *Statistics of Publicly Owned Electric Utilities in the United States — 1976*. DOE/EIA-0146.

U.S. Department of Energy, Grand Junction, Colo. 1979*a*. *Statistical Data of the Uranium Industry*. GJO-100(79).

U.S. Department of Energy. 1979*b*. *Environmental Development Plant — Uranium Enrichment*. DOE/EDP-0059.

U.S. Department of Energy. 1979*c*. *Uranium Enrichment Services Activity, Financial Statements for Period Ended September 30, 1978*. ORO-770.

U.S. Department of Energy. 1979*d*. *Monthly Energy Review*. DOE/EIA-0035/9(79).

U.S. Department of Energy. 1979*e*. *Statistics of Publicly Owned Electric Utilities in the United States — 1977*. DOE/EIA-0172.

U.S. Department of Energy. 1979*f*. *Statistics of Publicly Owned Electric Utilities in the United States — 1978*. DOE/EIA-0172(78). (October 1979).

U.S. Department of Energy. 1980. *Environmental Data — Energy Technology Characterizations, Vol. 2: Nuclear Fuel Cycle*. DOE/EV-0061/2.

U.S. Department of Health, Education, and Welfare. 1970. *Radiological Health Handbook*.

U.S. Department of the Interior, Denver, Colo. 1976. *Injury Experience in the Metallic Mineral Industries, 1972*. Informational Report 1042.

U.S. Department of the Interior, Denver, Colo. 1978*a*. *Injury Experience in the Metallic Mineral Industries, 1973*. Informational Report 1086.

U.S. Department of the Interior, Denver, Colo. 1978*b*. *Injury Experience in the Metallic Mineral Industries, 1974*. Informational Report 1087.

U.S. Department of the Interior, Denver, Colo. 1978*c*. *Injury Experience in the Metallic Mineral Industries, 1975*. Informational Report 1088.

U.S. Department of the Interior, Denver, Colo. 1978*d*. *Injury Experience in Coal Mining, 1972*. Informational Report 1074.

U.S. Department of the Interior, Denver, Colo. 1978*e*. *Injury Experience in Coal Mining, 1973*. Informational Report 1075.

U.S. Department of the Interior, Denver, Colo. 1978*f*. *Injury Experience in Coal Mining, 1974*. Informational Report 1076.

U.S. Department of the Interior, Denver, Colo. 1978*g*. *Injury Experience in Coal Mining, 1975*. Informational Report 1077.

U.S. Department of Labor. 1967. *Work-Injury Experience in Establishments Having Employees in Atomic Energy Work, 1965 and 1966*. BLS Report 334.

U.S. Department of Labor. 1968. *Work Injuries in Atomic Energy, 1967 — A Survey of Privately-Owned and -Operated Establishments*. Report 359.

U.S. Department of Labor. 1969. *Work Injuries in Atomic Energy, 1968 — A Survey of Privately-Owned and -Operated Establishments*. Report 378.

U.S. Department of Labor. 1970. *Work Injuries in Atomic Energy, 1969 — A Survey of Privately-Owned and -Operated Establishments.* Report 385.

U.S. Department of Labor. 1971. *Work Injuries in Atomic Energy, 1970 — A Survey of Privately-Owned and -Operated Establishments.* Report 411.

U.S. Department of Labor, Denver, Colo. 1978*a*. *Injury Experience in Coal Mining, 1976.* Informational Report IR 1097.

U.S. Department of Labor, Denver, Colo. 1978*b*. *Occupational Injuries and Illnesses in the United States by Industry, 1975.* Bulletin 1981.

U.S. Department of Labor, Denver, Colo. 1979*a*. *Injury Experience in Coal Mining, 1977.* Informational Report IR 1108.

U.S. Department of Labor. 1979*b*. *Occupational Injuries and Illnesses in the United States by Industry, 1976.* Bulletin 2019.

U.S. Department of Transportation, Transportation Systems Center. 1978. *National Transportation Statistics.* DOT-TSC-RSPA-78-13.

U.S. Department of Transportation, Transportation Systems Center. 1979. *National Transportation Statistics.* DOT-TSC-RSPA-79-19.

U.S. Energy Research and Development Administration. Undated. *Uranium Hexafluoride: Handling Procedures and Containment Criteria.* ORO-651.

U.S. Energy Research and Development Administration, Grand Junction, Colo. 1975. *Statistical Data of the Uranium Industry.* GJO-100(75).

U.S. Energy Research and Development Administration, Grand Junction, Colo. 1976*a*. *Statistical Data of the Uranium Industry.* GJO-100(76).

U.S. Energy Research and Development Administration. 1976*b*. *Final Environmental Statement on Expansion of U.S. Uranium Enrichment Capacity.* ERDA-1543.

U.S. Energy Research and Development Administration. 1977. *Uranium Enrichment Services Activity, Financial Statements for Period Ended September 30, 1976.* ERDA 77-27.

U.S. Nuclear Regulatory Commission. 1975. *Final Environmental Statement Related to the Kerr-McGee Nuclear Corp. Sequoyah Uranium Hexafluoride Plant, Docket No. 40-8027.* NUREG 75/007.

U.S. Nuclear Regulatory Commission. 1977. *Environmental Impact Appraisal of the Westinghouse Nuclear Fuel Columbia Site (NFCS) Commercial Nuclear Fuel Fabrication Plant, Columbia, South Carolina.* Unnumbered.

U.S. Nuclear Regulatory Commission. 1979. *Draft Environmental Statement Related to Operation of Gas Hills Uranium Mill, Union Carbide Corporation.* NUREG-0441.

Westinghouse Electric Corporation. 1979. *Alabama Nuclear Fuel Fabrication Plant Environmental Report.* Unnumbered.

Appendix A

METHODS FOR COLLECTING AND REPORTING OCCUPATIONAL SAFETY DATA

A major problem in making occupational risk assessments is the fact that occupational casualty data (injuries, illnesses, fatalities, and lost workdays) are collected and reported using various systems that are frequently incomparable. The incomparability is caused by differences in definitions of (1) which casualties (injuries and illnesses) are reportable or recordable, (2) how to classify a casualty, (3) how to charge lost workdays, and (4) the formats to be used for recording and reporting casualty incidence rates and severity rates. Another problem is that the definitions are changed from time to time. This appendix presents a brief historical perspective on the development of several of the data reporting systems, a discussion of the differences between the two principal systems, and an account of how we attempted to make the various systems comparable.

Prior to July 1, 1971, occupational casualty data were collected, recorded, and reported according to definitions given in American National Standards Institute (ANSI) Standards Z16.1 and Z16.2 (American National Standards Institute, Inc., 1969 and 1973). On July 1, 1971, most employers were required to collect and record occupational casualty data under definitions that satisfied the record-keeping requirements of the Occupational Safety and Health Act (OSHA) of 1970. Between 1971 and 1975, data were collected and recorded under both sets of definitions but usually were reported in the ANSI format. Since 1975, definitions (U.S. Department of Labor 1979, pp. 107–14) have been promulgated to meet revised record-keeping requirements of OSHA (U.S. Department of Labor, 1975). At that time, most government agencies began to collect, record, and report data under OSHA definitions or some variation thereof. However, many important sources of occupational casualty data [e.g., the National Safety Council (NSC) and the Mine Safety and Health Administration (MSHA), formerly the Mine Enforcement Safety Administration (MESA) of the U.S. Department of the Interior] did not embrace the OSHA definitions at that time. This produced a period of mixed-format reporting of occupational

casualty data that still persists. The NSC switched to the OSHA format on Jan. 1, 1977, and ANSI issued a memorandum describing how to make their format compatible with the OSHA format. Beginning with its 1978 data reports, MSHA has adopted a reporting format (see U.S. Department of the Interior, 1979, pp. 1–9) that is compatible with, but different from, the OSHA format. Some reporting agencies continue to use variations or parts of the OSHA or the ANSI system.

The net effect of changing reporting systems (more specifically, the definitions used by the systems), using dual systems, and using only parts of a system is to create confusion for persons attempting to use the data. Careful attention must be paid to the definitions under which data of interest were collected and reported. Once the definitional bases are understood, the data can be used properly. Then they can be cast into a form that permits combination and limited comparison of data that are based on different definitions, as we have done below and in the body of this report.

Since most occupational casualty data are reported under either OSHA or ANSI definitions (or a variation of either), we discuss differences between the systems below. Also, since the OSHA system is expected to find continued, widespread use, we describe the modifications necessary to make data reported under ANSI definitions compatible with data reported under OSHA definitions. However, it should be noted that this feat cannot always be achieved.

The ANSI system records and classifies casualties according to their severity — fatal, permanent total disability, permanent partial disability, temporary total disability, and nondisabling casualty. (Nondisabling cases are not always recorded.) This system of recording and classifying casualties is insensitive to any lost workdays involved. In contrast, the OSHA system records and classifies casualties as a direct function of lost workdays — (1) fatal, (2) nonfatal, involving days off from work and/or days of restricted work, and (3) nonfatal, not involving lost workdays or days of restricted work. (The latter category includes casualties requiring medical treatment beyond first aid and therefore counts many casualties not recorded under ANSI.) According to a study conducted by the National Safety Council (1979, pp. 2–5 and 42–43),

fatalities and disabling casualties recorded under ANSI definitions correspond, at least numerically, to fatalities and "lost-workday cases involving days away from work" recorded under OSHA definitions. The remaining OSHA classifications have no ANSI counterpart. Casualty data are presented as reported in the data tables that are given in this report. To make ANSI and OSHA data comparable, we define the casualty class "serious cases" to be either ANSI-defined nonfatal disabling casualties or OSHA-defined lost-workday cases involving days away from work. This casualty class is used to calculate the serious-case incidence rates that are given in the casualty incidence rate tables of this report.

Definitions of lost workdays under ANSI are totally incomparable with those under OSHA. ANSI records the numbers of days that workers are unable to work (even if not scheduled to work) because of temporary total disabilities. ANSI also assigns a prescribed number of chargeable days for fatalities (6000), permanent total disabilities (6000), and other disabilities (according to an injury-specific schedule). OSHA records actual workdays lost because of casualties causing absence from work and those resulting in restricted work assignments. OSHA does not charge time for fatalities or permanent total disabilities. We have not attempted to, nor can we, make the two lost-workday accounting systems comparable. Rather, we report, as appropriate, either total days away from work plus days of restricted activity (under OSHA) or chargeable lost workdays less 6000 days for each reported fatality and for each permanent total disability (under ANSI). This operation eliminates the large divergence between the systems caused by the different accounting of fatalities and permanent total disabilities.

ANSI computes incidence and severity rates as number of casualties or lost workdays per 10^6 man-hours. OSHA computes rates as numbers per 100 man-years (equal to 20,000 man-hours). We have converted all ANSI rates to the 100 man-year basis by dividing them by 5.

ANSI-based data that have undergone the above operations (treatment of lost workdays and division by 5) are called "modified ANSI" data. Mining and milling data, which are based on the Mining Enforcement and Safety Administration's interpretation of ANSI, have undergone the above operations and are designated as based on "modified MESA" definitions.

REFERENCES FOR APPENDIX A

American National Standards Institute, Inc. 1969. *American National Standard Method of Recording Basic Facts Relating to the Nature and Occurrence of Work Injuries*, ANSI Standard Z16.2-1962 (R1969).

American National Standards Institute, Inc. 1973. *American National Standard Method of Recording and Measuring Work Injury Experience*, ANSI Standard Z16.1-1967 (R1973).

National Safety Council. 1979. *Work Injury and Illness Rates*, 1979 ed.

U.S. Department of the Interior, Mine Safety and Health Administration. 1979. *Injury Experience in Coal Mining, 1978*, Informational Report IR 1112.

U.S. Department of Labor, Occupational Safety and Health Administration. 1975. *Recordkeeping Requirements Under the Occupational Safety and Health Act of 1970* (revised 1975).

U.S. Department of Labor, Bureau of Labor Statistics. 1979. *Occupational Injuries and Illnesses in the United States by Industry, 1976*. Bulletin 2019.

Appendix B

GLOSSARY

ANSI	American National Standards Institute, Inc.
BLS	Bureau of Labor Statistics
Btu	British thermal unit
BWR	boiling-water reactor
HF	hydrogen fluoride
HTGR	high-temperature gas-cooled reactor
HWR	heavy-water reactor
J	joule
kg	kilogram
kg-SWU	kilogram-separative work unit: a variable unit based on the work required to separate 1.272 kg of natural (0.71% ^{235}U) uranium into 0.232 kg of enriched (3% ^{235}U) uranium and 1.040 kg of depleted (0.20% ^{235}U) uranium tailings.
kW	kilowatt
kWh	kilowatt-hour
LMFBR	liquid-metal-fast breeder reactor
LWBR	light-water breeder reactor
LWDC	lost-workday case
LWD	lost workday
LWR	light-water reactor
MESA	Mining Enforcement and Safety Administration
MSHA	Mine Safety and Health Administration
MSWU	million separative work units (see kg-SWU)
MY	man-year (2000 man-hours)
NSC	National Safety Council
OSHA	Occupational Safety and Health Administration (or Act)
PJ	petajoule
SWU	separative work unit: the work required to enrich the ^{235}U content of feed uranium. It is a variable unit, which depends on the ^{235}U content of the feed material, the desired ^{235}U enrichment in the product, and the desired ^{235}U content of the depleted uranium residue (the tailings). The definition given under kg-SWU is the one used in this report.
TVA	Tennessee Valley Authority

TW	terawatt
TWh	terawatt-hour
U	uranium
^{235}U	The isotope of uranium with atomic weight equal to 235 atomic mass units.
UF_6	uranium hexafluoride
UO_2	uranium dioxide
U_3O_8	uranium oxide
USAEC	U.S. Atomic Energy Commission
USDOE	U.S. Department of Energy
USERDA	U.S. Energy Research and Development Administration
USNRC	U.S. Nuclear Regulatory Commission
W	watt