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ENERGY AND COMPLEX INDUSTRIAL SYSTEMS ENVIRONMENTAL EMISSIONS DATA REPORTING AND ACQUISITION

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Brookhaven National Laboratory

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1 INTRODUCTION

Estimates of types and quantities of emission from the introduction and use of energy and other complex technologies are needed to evaluate their risks. Although there is a large compiled literature on a range of energy technologies and emission types, the World Health Organization (WHO 1983a; 1983b), the United Nations Environment Program (UNEP 1985) and others (e.g., OECD 1984) have found that in developing quantitative assessments of health and environmental effects, that while these data are sometimes similar in different countries for a given technology, in most cases they vary due to differences in operating characteristics of fuel or material consuming devices, in fuel or material quality, or in regulatory-based pollution control requirements.

The Joint International Atomic Energy Agency (IAEA), UNEP and WHO Project on Assessing and Managing Health and Environmental Risks from Energy and Other Complex Technologies (Biomedical and Environmental Assessment Division 1985) aims to compile emissions data for important energy systems and other complex technologies from a wide variety of countries. To facilitate data generation and compilation, this report:

(i) outlines data reporting protocols;
(ii) identifies potential information sources;
(iii) demonstrates how to estimate coefficients;
(iv) presents some compiled U.S. emission coefficients for criteria air pollutants for some energy process; and,
(v) compares national air emission standards for electricity generating plants in OECD member countries.

2 DATA REPORTING PROTOCOLS

2.1 Definitions

Specification of the system boundaries is central to evaluating risks from energy systems and other complex technologies. In energy system analysis, these boundaries are often defined to include complete energy systems comprising activities ranging from extraction of fuel through to its intermediate conversion and ultimate end-use. To facilitate collection and transfer of data, a uniform set of terms must be adopted to describe such systems and their basic components. In this context, the terms -- process, activity, trajectory, and system -- were used by some energy system risk analysts (Council of Environmental Quality 1975).

A process is the smallest technological operation for which basic engineering and emission data are usually collected. Specific examples of processes associated with the coal and oil fuel cycles are given in Table 1.

An activity is the next level of aggregation. An activity is one or more processes that meet the same objective. Coal transportation is an activity because it can be accomplished by several different processes: unit and mixed train transport, barge, truck, slurry pipeline, or conveyor belt.

A trajectory is a linked series of processes from extraction to a specific end-use. An example is extraction of offshore oil, transportation to shore, refining, transportation to a retail gas station, and consumption in an automobile.

A system is a set of related trajectories. It may involve all uses of a particular resource, such as all coal trajectories from extraction to end use, or it may encompass the full national energy system, including all resources and all end-uses of energy.

These concepts for energy systems are illustrated in Figure 1; similar concepts for a material system are illustrated in Figure 2. In these figures, activities are identified across the top of the figure. Processes are indicated by the labeled horizontal lines. A trajectory involves one process from each activity, moving from left to right across the diagram. The supply side of any energy system depends on a particular fuel subsystem, which is the second level. Each fuel subsystem has an activity (or set of activities) associated with it, and within each activity there may be a process (or several processes). To summarize the format for supply:

First level : Supply
Second level : Fuel Subsystem
Third Level : Activity
Fourth level : Process

As an example, consider how longwall mining of coal should be described:

Supply : Supply
Fuel subsystem : Coal
Activity : Extraction (or mining)
Process : Longwall

The breakdown for any oil refinery would be as follows:

Supply : Supply
Fuel subsystem : Petroleum (or oil)
Activity : Crude oil processing
Process : Refining

The specific label for any particular process is chosen arbitrarily but it should be the most easily understood and most descriptive (e.g., mining vs. extraction for coal).

The end use of any energy system is categorized, at the second level, by a specific sector (residential, commercial, industrial, or transportation). Each sector consumes particular fuel types [the outputs of the fuel subsystem(s) available at a point of consumption], and each fuel type is consumed in a utilizing device. The format for end use can be described as:

First level : End use
Second level : Sector
Third level : Fuel type
Fourth level : Device

Automobile use would be described as follows:

End use : End use
Sector : Transportation
Fuel Type : Gasoline
Device : Automobile

The breakdown for a residential oil burner would be as follows:

End use : End Use
Sector : Residential
Fuel type : Distillate oil
Device : Space heater boiler

2.2 Scope

The scope of data to be compiled can vary by process and by pollutant. Processes being evaluated may need to be treated as one unified system, or as many independent subsystems. The degree of aggregation depends on the complexity of the facility in question, as well as on degree of dependence among process operations. Facilities which tend to be more complex and composed of many semi-independent operations require more disaggregation than simple integrated operations. In general, this dichotomy parallels the difference between energy-related vs. industrial-related activities.

Energy-related activities tend to focus on the processing or combustion of a fuel in a unified way. Industrial operations, however, may include many loosely aggregated activities which need to be evaluated independently.

As collection efforts are begun, some thought should be given to defining the system boundaries of interest (i.e., the back- and front-ends of the fuel and material supply cycles). In some instances, these contribute most of the emissions. Hence, the potential consequences of including or excluding them should be considered. As a general guide, complete cycles are often evaluated when systems are being compared, or when regional or national-scale analyses are being conducted. As the geographic or technologic scales of the analysis decreases, the value of including complete cycles diminishes.

Similarly, in assessing risks from these processes it might be appropriate to identify all pollutants from all alternatives. Practical limitations, however, quickly demand that effort be focused. Data collection could focus on any or all of the following:

(i) Pollutants for which there is acute (e.g., hydrogen sulfide) or chronic (benzo(a)pyrene) health effects dose-response information.

(ii) Pollutants which quantitatively dominate the waste streams (e.g., carbon monoxide from oil- or gas-fired steam electric power plants).

(iii) Index pollutants (e.g., BOD or sulfur oxides).

(iv) Pollutants for which there are environmental standards (e.g., lead in the atmosphere).

(v) Pollutants which are routinely or accidentally emitted (e.g., noble gases from a nuclear steam electric power plant).

Emission coefficients may range from simple point estimates to complex models. In generating simple and complex coefficients for specific activities, many underlying predictors may need to be defined. In combustion-based systems, for example, the following types of information must often be specified:

(i) energy content of fuel;

(ii) moisture, sulfur, ash and trace element (e.g., arsenic) content of fuel;

(iii) thermal efficiency of boiler;

(iv) temperature of exiting gases;

(v) type and characteristics of applied pollution-control equipment.

In industrial-based systems, all the aforementioned information must be examined. In addition rate of feedstock input and rate of product output may also need to be identified.

To the extent that these predictors are important contributors to the final coefficients and highly variable, they should be exogenous inputs to the emission coefficient, for example,

$$P = (8.5)(A)(P_e),$$

where

P = Particulate emissions from a bituminous coal-fired electric power plant,

A = Ash content of the bituminous coal, and

P_e = Efficiency of implemented fly-ash control equipment (e.g., electrostatic precipitators = 65 - 99.5%; High-efficiency cyclone = 30 - to 90%; low-resistance cyclone = 20 - 80%; settling chamber = 10 - 30%).

Coefficients such as those listed above are used to describe routine emissions quantitatively. Energy and other complex systems may also accidentally release toxic or hazardous materials. Identification and description of such coefficients often depends on detailed analysis of the process and on development of "what if scenarios." In these types of evaluations the following factors must often be considered: type of initiating event, quantity of toxic or hazardous material in inventory, chemical and physical reactions internal and external to the process, and type and efficiency of emergency pollution control systems.

In addition to pollutant emissions data, efforts may also be begun to collect data on direct impacts of a system or process on public and occupational health and safety. These impacts are often related to accidents affecting plant integrity or to inadequate industrial hygiene, safety or pollution control practices. Incidents may range from minor equipment failures to catastrophic releases of toxic or hazardous materials. These may be routine or infrequent. Similarly, effects from such incidents can range from minor injuries to long-term illness or death. Data from these incidents are often broken down into two major groupings: public and occupational. Within these groupings, data are often disaggregated into accident- or injury- and illness-related impacts.

Occupational illness refers to any abnormal condition or disorder, other than one resulting from an occupational injury, cased by exposure to environmental factors associated with employment. It includes acute and chronic illnesses or diseases which may be caused by inhalation, absorption, ingestion, or direct contact, and which can be included in the following categories: skin diseases or disorders; dust diseases of the lungs, respiratory conditions due to toxic agents; poisonings; disorders due to physical agents other than toxic materials; disorders due to repeated trauma; and, all other occupational illness.

Occupational injuries include injuries caused by work accidents or from exposure involving a single incident in the work environment. These are often recorded if they result in death, worktime lost, medical treatment other than minor first aid, loss of consciousness, restriction of work or motion, transfer to another job, or termination of employment.

Because of the availability of facility and insurance-related records, occupational injury-related impacts from energy and other complex industrial systems are almost always more easily identified than public impacts (with the exception of transportation and catastrophic industrial accidents). In the available actuarial data sets, public and illness-related impacts may not always be directly associated with a particular energy or industrial activity. Illnesses related impacts are particularly troublesome because the recording and reporting of illnesses continue to present measurement problems since employers and doctors are often unable to recognize some illnesses as being related to a particular industrial activity as well as the long latency involved in many diseases.

Data on these impacts, like those for environmental pollutants, may be influenced by many different factors which are not easily quantified: plant age, maintenance, and industrial hygiene and safety practices. Similarly, effects may vary among different worker types (e.g., production vs. maintenance vs. administrative) as well as by work-station and work-shift. Data collection in this area may include:

(i) Occupational health impacts (i.e., exclude public health).
(ii) Injury-related impacts (i.e., exclude illness-related).

2.3 Format

In the technical literature, many formats are used to express emissions data for different processes:

(i) mass of pollutant per mass of fuel (g/kg);
(ii) mass of pollutant per mass of product (g/kg);
(iii) mass of pollutant per unit time (g/hr);
(iv) mass of pollutant per unit activity (g/km);
(v) mass of pollutant per unit of volume (g/m^3);
(vi) mass of pollutant per unit of energy input or output (g/J).

Reporting protocols differ, in part, because of historical and regulatory reasons. In the U.S. and elsewhere (see OECD 1985), emissions from energy-related activities (i.e., combustion sources) are regulated on a pollutant mass per unit of energy input (i.e., g/J) or on a pollutant mass per unit of volume (g/m3) basis. Emission standards for non-combustion sources associated with industrial activities span the range of reporting protocols listed above.

Although it may be possible to interconvert among all of these reporting protocols, it may not always be practical. More importantly, such conversions often depend on assumptions including energy and inherent pollutant (e.g., ash or sulfur) content of the combusted fuel, exhaust gas volumes, firing rates of the fuel consuming unit or use of pollution control equipment.

There are several commonly used protocols for reporting occupational injuries and illnesses: incidence rates, lost workday cases, lost workdays, and fatalities. As defined by the U.S. Department of Labor (1979), incidence rate refers to the number of injuries, illnesses, lost workdays or fatalities experienced per 100 full-time workers. The rate is calculated as:

$$N/EH * 200{,}000,$$ where

N = number of occupational illnesses, injuries, lost workdays, or fatalities,
EH = total hours worked by all employees during the calendar year,

200,000 = base for 100 full-time equivalent workers (40 hrs/wk * 50 wks/yr).

Two measures are currently used as estimates of worktime lost: "*lost workday cases*" primarily measure the occurrence of injuries, and "*workdays lost*" which indicate the severity of the cases. Lost worktime includes both days away from work and days of restricted work activity. "*Lost workday cases*" involving days away from work include those cases which result in days away from work, or a combination of days away from work and days of restricted work activity. Lost workday cases involving restricted work activity only occur when the employee reported to work, but could not perform all the duties of the job.

Like emission coefficients, incidence rates may need to be transposed into commonly defined units for use in energy/technology risk assessment. Usually, this requires estimates of the amount of labor required to perform a particular activity.

3 DATA SOURCES

Information can be collected from government and private organizations, from compiled literature, from new engineering estimates, or from new measurements. As noted by WHO (1982), "A major task of the study team is to locate all major government information sources and to extract the required data from them." A partial list of possible sources of information is in Table 2. Undoubtedly, a sizeable portion of the required information available from these organizations will be in unpublished form. Therefore, some efforts will needed to have useful information, extracted, processed, and classified. The major difficulties with unpublished data are determining which are needed and then interpreting the selected data. Often there is a danger of omitting important information if screening is not done carefully. On the other hand, complexity and resource requirements increase considerably if relatively unimportant data are retrieved and processed. Focusing data collection activities by approaches similar to those listed in Section 2.2 will certainly help minimize collection efforts, while ensuring the usefulness of the final results. Cross-checking collected data with information from other sources is often possible and highly desirable, since it is one way of insuring accuracy of the results. If important data from various sources are in significant disagreement, investigation of their original derivation often provides a good basis for formulation of the most accurate estimates.

In the event that the agencies listed in Table 2 have not compiled the needed information, first-order approximations of the engineering and environmental characteristics for most energy systems and for most conventional air (e.g., PM, SOx, NOx) and water (e.g., TDS, BOD, pH) pollutants can be derived from several summary documents (e.g., Hittman 1974; The Science and Public Policy Program 1975; Office of Air and Waste Management 1977; Office of Environmental Engineering and Technology 1980; The Aerospace Corporation 1981; The Aerospace Corporation and Mueller Associates, Inc. 1983; Manthey et al. 1980; Hubert et al., 1981; WHO 1983a; WHO 1983b; UNEP 1985; OECD 1984). Emission data on many industrial processes for conventional pollutants have been evaluated by WHO (1982) for the "Rapid Assessment of Sources of Air, Water, and Land Pollution" and by the U.S. Environmental Protection Agency to establish air and water pollutant emission standards. Tables 3 and 4 summarize the industries and pollutants examined in the EPA efforts. EPA efforts have also focused on some toxic chemicals (Table 5).

More detailed characterization efforts may be required for any of the following reasons:

(i) development of site-specific case studies;

(ii) analysis of indigenous energy systems (e.g., peat or dung) or industrial activities which are not used widely;

(iii) nonconventional (e.g., toxic or hazardous) pollutant emission coefficients;

For these characterizations, data gathering efforts may need to focus on technical literature published by various research (e.g., U.S. Department of Energy) or regulatory organizations (e.g., U.S. Environmental Protection Agency), as well as by equipment manufacturers. In the event that such literature does not exist, two alternatives remain. First, is to prepare design engineering estimates based on stoichiometric calculations. Second, is to implement field programs to measure the emission streams from existing facilities. If coefficients are based on existing literature, questions will always remain about the accuracy and precision of the extrapolation. Similarly, stoichiometric estimates may be erroneous because of inadequate specification or understanding of the process or knowledge. Finally, measurements require substantial time and effort for their collection. Furthermore, if substantial data are not collected, they may not be representative of the true emission characteristics because of time and process dependent variations.

Data on occupational injuries and illnesses are compiled by international (e.g., International Labour Organisation 1986), national (e.g., U.S. Department of Labor - Bureau of Labor Statistics 1978), state (e.g., California Department of Industrial Relations 1983) and private organizations (e.g., The National Safety Council 1986). In general, they report injury and illness incidence rates by 2, 3 or 4 digit Standard Industrial Classification (SIC) Code (Statistical Policy Division, 1972): for example, Petroleum and Coal Products (SIC 29), Paving and Roofing Material (SIC 295), and Asphalt Felts and Coatings (2952). Similarly, the International Labour Organisation, the National Institute for Occupational Safety and Health, the Occupational Safety and Health Administration, the Mine Safety and Health Administration and other organizations also publish detailed reports focusing on occupational hazards to workers in selected industries. Reports and statistics published by these organizations can provide detailed descriptive and quantitative data on hazards workers may encounter.

In developing estimates of occupational health impacts of the energy or complex industrial systems from such data, several problems will arise. First, published incidence rates may not be representative of the occupational health experience of similar industries in other countries (Morris 1981; Baum and Horan 1985). Second, actuarial data may not be available for new systems. Third, the accuracy of illness-related statistics is limited. All of these issues present barriers to developing accurate occupational health impact coefficients.

Data on public health impacts from various activities are also compiled by international (WHO), national and state (e.g., National Center for Health Statistics 1987), and private organizations (The National Safety Council 1986). In some instances, these can be related directly to energy or industrial activities (e.g., transportation-related accidents); these for the most part are accident or injury-related incidents. The actuarial data base for estimating public health impacts from energy and other complex technologies is limited.

4 SAMPLE CALCULATIONS

Summarized below are sample collection and analysis efforts required to develop two different types of emission coefficients: SOx and particulate (TSP) emissions from coal-fired steam electric power plants; and, public and occupational injuries and fatalities from coal transportation by truck. The first is an example of the approach to calculate routine emission coefficients. The second is an example of an approach to calculate health impact coefficients.

4.1 SOx and TSP Emissions from a Coal-Fired Steam Electric Power Plant

There is a large difference in designs, particularly with respect to firing method among coal-fired steam electric generators. Coal can be fired by pulverization and burning in suspension, by combustion in cyclone furnaces, or by stoking. In pulverized coal boilers, used most often by utilities, coal is blown into the furnace. In comparison, in cyclone furnaces, coal is fed into the top, where it immediately encounters the turbulence of the "cyclone" which causes long residence time and thorough combustion. In stoker-fired boilers, coal enters the firebox on moving grates. In all three systems, heat from combustion gases is transferred to water circulating in boiler tubes. Water is heated to near boiling point at high pressure; it then flows through a series of drums and tubes where it is vaporized to staturated steam. Turbines convert the heat energy contained in the steam to mechanical energy for turning generators which produce electricity.

To estimate routine emission characteristics from such energy systems, some basic design engineering information must be defined:

(i) net power to be delivered to the transmission grid (P) in MWe;
(ii) net station heat rate (R) in Btu/kWh;
(iii) heat content of coal, as fired (Q) in Btu/lb.

In the U.S., a survey (O'connor 1978) showed that a typical utility plant would have the following characteristics: 500 MWe pulverized coal plant with an electrostatic precipitator to control TSP emissions and a wet lime/limestone scrubber for flue gas desulfurization. The plant would have a net station heat rate of 9760 Btu/kWh, which corresponds to an overall efficiency of 35%. In this composite plant, the coal used is eastern bituminous with a heat value of 12,000 Btu/lb, 3.3% sulfur and 8.8% ash.

Using the above definitions, the coal feed rate (F) required on a daily basis would be calculated as follows:

$$F = (PR/Q)[(1000\ \text{kWe/MWe})(1\ \text{ton}/2000\ \text{lbs})(24\ \text{hrs/day}]$$
$$= (PR/Q)(12)$$

Thus, for the representative plant:

$$F = (500\ \text{MWe})(9760\ \text{Btu/kWh})(12)/(12{,}000\ \text{Btu/lb})$$
$$= 4900\ \text{tons/day}$$

Among the many pollutants emitted by this facility, SOx and TSP have attracted great attention because of their health and environmental significance. Sulfur oxides are emitted when coal is burnt, and the sulfur in the coal is converted into SO_2 with small amounts of SO_3 also being formed. The SO_2 and SO_3 exit the boiler in the flue gas stream and are discharged to the atmosphere unless some form of SOx control is applied. According to the U.S. EPA - Office of Air and Waste Management (1977), the SOx emission factor for bituminous coal combustion in a furnace with a heat input greater than 10^8 Btu/hr without control equipment is

$$E_s = 38\ (S)$$

where,

E_s = Sulfur oxide emissions in lbs/ton of coal burned,

S = Sulfur content of the fuel.

Hence,

$$E_s = 38\ (3.3)$$
$$= 125.4$$

Thus, on a daily basis, the representative uncontrolled power plant would emit

$$S_u = (Es)(F)$$
$$= (125.4\ \text{lbs/ton})\ (4900\ \text{tons/day})$$
$$= 614460\ \text{lbs}$$

where,

S_u = daily uncontrolled SOx emissions.

The most popular operational control device for SO_2 is the wet lime/limestone scrubber. In this device, the SO_2-ladened flue gas is brought into contact with a solution or slurry of lime or limestone and water. The SO_2 reacts with the lime or limestone ($CaCO_3$) slurry to form $CaSO_3$ and $CaSO_4$ which remain in the scrubbing liquid and are eventually removed from the system in a thickener as a waste sludge. The major controlling factors for determining the efficiency of SO_2 removal in a scrubber are degree and duration of contact between scrubbing slurry and the flue gas and reactivity of the scrubbing slurry. Increases in removal efficiency can also be accomplished through increases in the stoichiometric ratio of sorbent to sulfur at the expense of higher operating costs. In general, however, these devices can routinely reduce SO_2 emissions by 80%. Consequently, controlled emissions from the power plant are:

$$S_c = (S_u)\ (1-S_e)$$

where,

S_c = The controlled sulfur emissions in lbs,

S_e = The scrubber efficiency

Hence,

$$S_c = 614460 \text{ lbs } (1-0.80)$$
$$= 122893 \text{ lbs}$$

If this plant were to comply with EPA New Source Performance Standards promulgated under the authority of the Clean Air Act, allowable emissions would range from 1.2 lb $SO_2/10^6$ Btu input to less than 0.6 lb $SO_2/10^6$ Btu input. The reason that the NSPS is variable is that the standard is defined in terms of percentage reductions: if uncontrolled emissions exceed 12 lb $SO_2/10^6$ Btu input, then greater then 90 percent reduction in SO_2 emissions is required; if uncontrolled emissions range from 12 - 6 lb $SO_2/10^6$ Btu input then a constant 90 - 70 percent reduction in SO_2 is required; if uncontrolled emissions range from 6 - 2 lb $SO_2/10^6$ Btu input then a variable 90 to 70 percent reduction in emissions is required; and if uncontrolled emissions are less than 2 lb $SO_2/10^6$ Btu input then a constant 70 percent reduction in SO_2 emissions is required.

In the example calculation,

$$S_r = (S_u)(10^6)/[(F)(12000 \text{ Btu/lb})(10^6)]$$

where,

S_r = SO_2 emission rate in lb/106 Btu in.

Hence,

$$\begin{aligned} Sr &= (614460\ \text{lb})(10^6)/[(4900\ \text{tons})(12000\ \text{Btu/lb}) \\ &\quad (2000\ \text{lb/ton})(10^6)] \\ &= (614460\ \text{lb})(10^6)/[(1.2 \times 10^{11}\ \text{Btu})(10^6)] \\ &= 5.2\ \text{lb}/10^6\ \text{Btu}. \end{aligned}$$

Consequently, these emissions would need to be reduced by 70 - 90 percent. The controlled emission coefficient for this facility would then range from:

$$\begin{aligned} S_c &= (S_u)\ (1-S_e) \\ S_c &= 614460\ \text{lbs}\ (1-0.90) \\ &= 61446\ \text{lb} \end{aligned}$$

to,

$$\begin{aligned} S_c &= (S_u)\ (1-S_e), \\ &= 614460\ \text{lb}\ (1-0.70) \\ &= 184338\ \text{lb} \end{aligned}$$

When coal is burned in pulverized-coal boilers, as much as 80 percent of the ash in the coal leaves the combustion chamber entrained in combustion gases as fly ash particulate (TSP) material. Particulate emissions can be calculated in a way similar to that for SO_2. According to the U.S. EPA - Office of Air and Waste Management (1977), the TSP emission factor for bituminous coal combustion in a furnace with a heat input greater than 10^8 Btu/hr without control equipment is

$$E_p = 16\ (A)$$

where,

E_p = particulate emissions in lbs/ton of coal burned,

A = ash content of the fuel.

Hence,

$$\begin{aligned} E_p &= 16\ (8.8) \\ &= 140.8\ \text{lb} \end{aligned}$$

Thus, on a daily basis, the representative uncontrolled power plant would emit

$$\begin{aligned} P_u &= (E_p)(F) \\ &= (140.8\ \text{lbs/ton})\ (4900\ \text{tons/day}) \\ &= 68992\ \text{lbs} \end{aligned}$$

where,

P_u = daily uncontrolled particulate emissions.

Fly ash or TSP emissions can be effectively controlled by various control alternatives (e.g., electrostatic precipitators, high efficiency cyclones, settling chamber expanded chimney base). The most popular operational control device for fly ash is the electrostatic precipitator. This device charges the individual particles in the gas stream using a high-voltage field (20 - 100 kV). The particles are attracted to and captured by oppositely charged collector plates. The particles are removed from the plates and collected for disposal by several methods, the most common of which is "rapping." These devices can be expected to remove up to 99.5 percent of the entrained fly ash. The particulate loading to the atmosphere can be calculated by:

$$P_c = (A/100)\ (A_f)\ (F)\ (1\text{-}P_e)$$

where,

P_c = The controlled particulate emissions in lbs,

A_f = The fly ash fraction typically assumed to be 0.80,

Pe = The efficiency of the control device.

Hence,

$$P_c = (8.8/100)\ (0.8)\ (4900 \text{ tons/day})\ (1\text{-}0.995)$$
$$= 1.7 \text{ tons/day}$$

If this plant were to comply with EPA New Source Performance Standards promulgated under the authority of the Clean Air Act, allowable emissions would be 0.03 lb particulates/10^6 Btu input. Controlling particulates to this level would give:

$$P_c = (0.031\text{b}/106 \text{ Btu})(4900 \text{ tons/day})(12000 \text{ Btu/lb})\ (2000 \text{ lb/ton})$$
$$= 3528 \text{ lb/day}$$

4.2 Health Impacts of Coal Transportation by Truck (from Morris 1983)

In the U.S., truck transportation is the most rapidly growing mode of coal transport. Twelve percent of the total coal production, or about 8 x 10^7 tons, is delivered by truck. Haul distances average 50 - 75 miles (Congressional Research Service 1977). This does not include truck-haul of coal to tipples for loading on rail or barges. Morris assumes a 30-ton load of coal per trip, giving an average trip load of 15 tons, including the empty return trip. Common carrier truck fleets average 7 accidents per 10^6 vehicle mile (National Safety Council 1978). Similarly, it was estimated that there are 0.03 deaths and 0.5 injuries per accident. Thus, the number of deaths (D) and injuries (I) for the representative 500 MWe power plant which requires 1.4 x 10^6 tons per year of coal [(4900 tons/day)(365 days/yr)(0.8 capacity factor)] results in:

$$D = (7 \text{ accidents}/10^6 \text{ trip miles})\ (0.03 \text{ deaths/accident})$$
$$(1.4 \times 10^6 \text{ tons per year of coal})/(15 \text{ ton miles/trip})$$
$$= 1.96 \times 10^{-2} \text{ deaths,}$$

and

$$I = (7 \text{ accidents}/10^6 \text{ trip miles})(0.5 \text{ injuries/accident})$$
$$(1.4 \times 10^6 \text{ tons per year of coal})/(15 \text{ ton miles/trip})$$
$$= 3.2 \times 10^{-1} \text{ injuries.}$$

These are assumed to be split equally between employees and the public.

5 A COMPILATION OF U.S. EMISSION FACTORS

Table 6 gives emission coefficients for five conventional air pollutants (i.e., SOx, NOx, CO, HC, and TSP) for a range of energy systems. These are compiled from a report prepared for the U.S. Department of Energy (The Aerospace Corporation and Mueller Associates, Inc. 1983). Detailed documentation needed to define the bases for these numbers are contained in that report. Although these data provide some perspective on the coefficients for similar activities elsewhere, the true coefficients will differ, perhaps in major ways, for some or all of the following:

(i) process applications will vary in terms of their engineering characteristics (e.g., size, efficiency, temperature);

(ii) fuel supply to the process will have different characteristics (e.g., heat, sulfur and ash content);

(iii) pollution control equipment added to the process will have different impacts (e.g., efficiency or on types of pollutants scrubbed).

Thus, extrapolation and application of these coefficients to other countries may introduce large errors unless these factors are examined.

6 EMISSION STANDARDS FOR ENERGY FACILITIES IN OECD COUNTRIES

Table 7 gives emission standards for electric generating plants for OECD countries (OECD 1984). The base reporting protocols for these coefficients vary among the different countries (i.e., pollutant weight per unit of energy input or output, or as a concentration in the flue gas). As discussed by OECD, simply reporting the standards on one uniform basis (i.e., ng/J input) may introduce error because of underlying assumptions that must be made (e.g., temperature and moisture content of the flue gas). Other variations may also exist (e.g., actual vs. normalized stack conditions, weighted vs. rolling averages). Consequently, comparisons among the different coefficients should be viewed with caution. Nevertheless, certain general conclusions were noted:

> "...Maximum values for particulate emissions for the countries presented tend to be fairly similar, especially for solid fuels. This reflects the fact that particulate control technology has been well developed for some years and high collection efficiencies are possible with off the shelf units...
>
> The situation with regard to sulphur oxide emission standards is more complex with many countries preferring to control sulphur content of fuels. The standard imposed reflect a number of factors, among them are:
>
> (i) Length of time since last review of regulation as the means of higher levels of SOx control have only recently become commercially available;
> (ii) Internal and external pressures to reduce SOx emissions. Comparatively isolated, under populated and less industrialized countries are less likely to take legislative action to force the imposition of a relatively expensive form of environmental control;
> (iii) Attitudes of policymakers towards the technical and economic viability of a comparatively new control option.
>
> Nitrogen oxide emission standards are less varied. They tend to reflect the current state of technology in NOx control during combustion in most countries. There is, however, a tendency in some countries, for NOx control standards to be technology-forcing, particularly

> control standards to be technology-forcing, particularly with reference to the development of flue gas denitrification."

7 DISCUSSION AND RECOMMENDATIONS

(To be developed by Working Group. Discuss format, scope, emissions, and identify which emission coefficients are appropriate for application in other countries and for what reasons)

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Table 1. Representative Process Alternatives in the Coal and Oil Fuel Cycles.

- Coal
  - Longwall mining
  - Cleaning
  - Transport by rail, barge, ship, and truck
  - Coal-fired steam electric power plant
  - Local distribution
  - Residential and commercial coal boilers
  - Residential coal space heating stoves (vented)
  - Residential coal burning (unvented)

- Oil
  - On-shore production
  - Off-shore production
  - Transport by tanker, pipeline or truck
  - Refining
  - Residual oil transport and storage
  - Oil-fired steam electric power plant
  - Distillate oil transport and storage
  - Distillate oil commercial and residential heating
  - Distillate oil stationary diesel engines
  - Distillate oil mobile diesel engines
  - Gasoline transport and storage
  - Gasoline automobile use

Table 2. Possible Sources of Information.[1]

Type of Data	Possible Sources
Industrial activity	Ministry of industry or commerce National planning or economic development agencies Electric energy ministry, authority or company Internal revenue agencies Local governments Industry associations Ministry of animal production Air, water, and solid waste pollution control authorities
Fuel consumption	Ministry of energy Ministry of industry Internal revenue agencies Refineries or oil distribution companies
Rail and road traffic activity	Ministry of transportation
Air traffic activity	Airport authorities Ministry of transportation
Shipping activity	Port authorities Ministry of transportation
Water emissions	Oceanographic institute Ministry of health or environment River authorities Water pollution control authorities Ministry of fisheries Area planning agencies Local health departments Universities
Air emissions	Ministry of health or environment Air pollution control authorities Universities
Solid wastes	Local authorities Ministry of environment Private refuse disposal companies Area planning or development agencies
Occupational health	Ministry of health Local health departments Universities

Table 2 (cont).

Public health	Ministry of health Local health departments Universities

1. Modified from WHO 1982.

Table 3. Industries for Which U.S. Environmental Protection Agency New Source Performance Standards for Air Pollutants Have Been Developed.

Industry	Pollutants Regulated
Fossil-fueled steam generators	PM, SO_2, NOx
Incinerators larger than 50 TPD	PM
Portland cement plants	PM, Opacity
Coal preparation facilities	PM, Opacity
Nitric acid plants	NOx, Opacity
Primary aluminum smelters	F, Opacity
Sulfuric acid plants	SOx, Acid Mist, Opacity
Asphalt concrete plants	PM, Opacity
Sewage sludge incineration	PM, Opacity
Iron and steel plants	PM, Opacity
Electric arc furnaces	PM, Opacity
Ferroalloy production facilities	PM, CO
Secondary brass and bronze ingot	PM, Opacity
Kraft pulp mills	PM, Total Reduced Sulfur
Petroleum refineries	PM, Opacity, CO, SO_2
Storage vessels for petroleum	VOC
Secondary lead smelters and refining	PM, Opacity
Primary copper, lead and zinc	PM, SO_2, Opacity
Phosphate fertilizer industry	F
Grain elevators	PM, Opacity
Ammonium sulfate manufacture	PM, Opacity
Lead acid battery manufacture	Pb, Opacity
Stationary gas turbines	NOx, SO_2,
Glass manufacturing	PM
Phosphate rock plants	PM, Opacity
Synthetic organic chemicals	VOC
Pressure-sensitive tape and label coating	VOC
Auto and light truck surface coating operations	VOC
Asphalt processing and asphalt roofing manufacture	PM, Opacity
Rotogravure printing	VOC
Bulk gasoline terminals	VOC
Beverage can coating	VOC

Acronyms: PM - Particulate Matter; VOC - Volatile Organic Carbon

Table 4. Industries for Which U.S. Environmental Protection Agency Pretreatment and Effluent Guidelines and Standards for Water Pollutants Have Been Developed.

Industry	Pollutants Regulated
Beet sugar	BOD, TSS, pH
Cane sugar	BOD, TSS, pH
Fiberglass insulation mfg.	Phenol, COD, BOD, TSS, pH
Sheet, plate and laminated glass	TSS, pH, O&G, P, F, Pb, Ammonia
Rubber processing	TSS, O&G, pH, BOD, COD
Asbestos mfg.	COD, TSS, pH
Meat products	BOD, TSS, O&G, Fecal Coliform, Ammonia
Phosphate mfg.	TSS, Phosphorus, As, pH, F
Fruit and vegetable processing	BOD, TSS, pH
Plastics and synthetics	BOD, COD, TSS, pH, Cr, Zn, Phenols, O&G
Nonferrous metals	TSS, F, Ammonia, Al, Cu, COD, pH, O&G, As, Cu, Pb, Cd, Se, Zn
Timber products	BOD, TSS, pH, Phenols, O&G, Cu, CR, As
Organic chemicals	COD, BOD, TSS, pH, Phenols, Cyanide
Leather tanning & finishing	BOD, TSS, O&G, Cr, pH, Sulfide
Petroleum refining	BOD, TSS, COD, O&G, pH, Phenols, Ammonia, Sulfide, Cr
Pulp, paper and paperboard mfg.	BOD, TSS, pH, Pentachlorophenol, Trichlorophenol, Zn
Builders' paper and roofing felt	BOD, TSS, pH, Pentachlorophenol, Settleable Solids, Trichlorophenol
Iron & steel mfg.	TSS, O&G, Ammonia, CN, Phenols, pH, Benzene, Naphthalene, Benzo(a)pyrene, TRC, Pb, Zn, Ni, Cr, Tetrachloroethylene
Textiles	BOD, TSS, COD, O&G, Cr, pH, Phenol, Sulfide, Color, Fecal Coliform
Steam electric power plants	TSS, O&G, Cl, Cu, Fe, Cr
Paint formulating	No discharge of process waste
Ink formulating	No discharge of process waste
Paving and roofing materials	O&G, pH, TSS, BOD
Offshore oil & gas extraction	Produced water, deck drainage, Drilling muds, Drill cutting, Well treatment, Sanitary, Domestic, Produced sand
Mineral mining & processing	pH, TSS, F, Fe
Coal mining & processing	Fe, Mn, TSS, pH, Settleable Solids
Pharmaceutical mfg.	CN, COD, BOD, TSS, pH
Metal finishing	CN, Cd, Cr, Cu, Pb, Ni, Ag, Zn, TTO, O&G, TSS, pH

Table 4 (cont).

Coil coating	Cr, CN, Zn, Fe, O&G, TSS, pH, P, Mn, TTO
Porcelain enameling	Cr, Pb, Ni, Zn, Al, Fe, O&G, TSS, pH, Ammonia, Phenols, CN
Copper forming	Cr, Cu, Pb, Ni, Zn, O&G, TSS, F, As, pH, TTO, Cd, As
Aluminum forming	Cr, CN, Zn, Al, O&G, TSS, pH, TTO,
Ore mining & dressing	TSS, Fe, pH, Al, COD, As, Zn, Ra226, NH, U, Cd, Cu, Pb
Explosives mfg.	COD, BOD, TSS, pH, O&G
Hospitals	
Gum & wood chemicals mfg.	BOD, TSS, pH
Photographic processing	Ag, CN, pH
Pesticide mfg.	COD, BOD, TSS, Organic Pesticides, pH
Electroplating	CN, Pb, Cd, Ni, Cr, Zn, Total Metals, TSS, pH Ag, TTO,
Dairy processing	BOD, TSS, pH
Grain mills	BOD, TSS, pH
Canned & preserved seafood processing	BOD, TSS, O &G, pH
Cement mfg.	TSS, Temperature, pH
Feedlots	Fecal Coliform, BOD
Soap and detergent mfg.	BOD, COD, TSS, O&G, pH, Surfactants
Fertilizer mfg.	P, F, TSS, Ammonia, N
Phosphate mfg.	P, F, pH, TSS
Ferroalloy mfg.	TSS, Cr, Mn, pH, CN, Phenols, Ammonia
Asbestos products mfg.	TSS, pH, COD
Electrical and electronic components	TTO, F, pH, As, TSS,
Inorganic chemicals	TSS, pH, Zn, Hg, Cu, Pb, Ni, Cl, TOC, CN, Cr, Fe, COD, Se, Ba, Sulfide, Ag

Acronyms: TSS = Total Suspended; COD = Chemical Oxygen Demand; BOD = Biological Oxygen Demand; O&G = Oil and Grease; TTO = Total Toxic Organics; TOC = Total Organic Carbon

Table 5. Pollutants and Activities for Which U.S. Environmental Protection Agency Hazardous Air Pollutant Emission Standards Have Been Developed.

- Asbestos
  - Asbestos mills
  - Roadway surfacing
  - Manufacture of cloth, cord, wicks, tubing, tape, twine, rope, thread, yarn, roving, lap, or other textile materials, cement products, fireproofing and insulating materials, friction products, paper, millboard and felt, floor tile, paints, coatings, caulks, adhesives, plastics, rubber materials, chlorine, shotgun shells, and asphalt concrete
  - Demolition and renovation
- Beryllium
  - Extraction plants, ceramic plants, foundries, incinerators, propellant plants, rocket motor test sites and machine shops
- Mercury
  - Stationary sources which process mercury ore to recover mercury, use mercury chlor-alkali cells to produce chlorine gas and alkali metal hydroxide, and incinerate or dry wastewater treatment plant sludge
- Vinyl Chloride
  - Plants which produce ethylene dichloride by reaction of oxygen and hydrogen chloride, vinyl chloride by an process, and or one or more polymers containing any fraction of polymerized vinyl chloride.
- Benzene
  - Fugitive emission source, coke by-product plants
- Radionuclides
  - DOE facilities, NRC-licensed facilities, elemental phosphorus plants
- Inorganic Arsenic
  - Low and high arsenic copper smelters

Table 6. Emission Coefficients for Criteria Air Pollutants from Various Energy Technologies.[1]

		AIR POLLUTANTS, tons/10^{12} BTU					
TECH.	ACTIVITY	SOx	NOx	CO	HC	TSP	Comments
Nuclear							
	Open Pit Uranium Mining	0.43	0.25	0.00	0.02	0.27	Open pit mining of ore for fuel
	Underground Uranium Mining	0.02	0.32	0.19	0.03	0.01	Underground mining of ore for fuel
	Uranium Milling	0.01	0.41			5.40	Milling ore to yellowcake (U_3O_8)
	Hexafluoride Conversion	1.30	0.46	0.01	0.04		Yellowcake to UF_6
	Gaseous Diffusion	197.00	51.80	1.30	0.50	51.80	Enrichment to 4% U-235
	Gas Centrifuge Enrichment	0.46	0.37	0.01		0.02	Enrichment to 2-4% U-235
	Fuel Fabrication	1.10	0.28	0.01			UF_6 to UO_2 fuel elements
	Commercial Waste Repository	0.27	0.42	0.38	0.03	0.02	Construction and Operations Emissions
Coal							
	Eastern Underground Mining	0.03	0.31	0.08	0.02	0.02	With preparation plant; diesel emissions
	Eastern Surface Mining	2.55	3.50	7.30	2.27	1.81	With preparation plant
	Western Surface Mining	0.32	4.80	0.97	0.30	0.96	With prep. plant; TSP incl. fugitive dust
	Beneficiation	0.01	0.60	0.20	0.20	0.90	Cleaning process
	Dedicated Rail, eastern	3.70	3.20	3.40	2.50	102.90	4 diesels, 90 trips/yr.
	Dedicated Rail, western	5.00	4.40	4.60	3.60	140.00	4 diesels, 90 trips/yr.
	Conventional Rail, eastern	2.60	2.90	0.50	2.00	102.00	1 diesel, 20 trips/yr;(other cargo)
	Conventional Rail, western	3.50	4.00	3.70	2.70	138.40	1 diesel, 20 trips/yr;(other cargo)
	Barge Transport, eastern	0.52	7.71	1.68	0.62	0.55	1 diesel tug, 22040 miles/yr.
	Barge Transport, western	1.47	22.03	4.79	1.76	1.57	1 diesel tug, 26889 miles/yr.
	Truck Transport, eastern	0.29	1.87	2.95	0.47	35.16	1 trailer, 1.2 x 10^6 net ton miles
	Fluidized Bed, bituminous	1440.	366.00	56.00	15.00	138.00	Steam plant with emission controls
	Fluidized Bed, subbitum.	1700.	582.00	90.00	30.00	146.00	Steam plant with emission controls
	Coal-Oil Power Plant	1297.	648.00	40.00	18.00	144.00	40/60 mix (by wt.) coal/oil
	Coal-Fired Plant, eastern	850.00	850.00	60.00	18.00	42.00	Mine-mouth steam plant;emission controls
	Coal-Fired Plant, western	600.00	850.00	90.00	30.00	40.00	Conv. steam plant; emission controls
Petroleum							
	Primary Oil Extraction	13.60	18.60	0.50	10.60	3.50	Emissions from drilling/production
	Enhanced Oil Recovery	207.00	71.00	4.00	2.00	24.00	Recovery via steam injection
	Offshore Oil Extraction	11.79	31.92	6.91	2.55	2.28	18 platforms; 4000 bbl/day
	Crude Oil Storage				2.27		Lined salt-dome caverns
	Oil-Fired Power Plant	3720.	432.00	49.30	9.80	410.00	Steam plant with emission controls
Gas							
	Onshore Gas Extraction	1425.	84.70	1.90	0.60	1.90	120 gas wells
	Offshore Gas Extraction	300.00	0.15	0.06	0.01		18 well platform; 88.7 x 10^6 cu. ft/day
	Natural Gas Purification	0.01	40.90	0.00	0.36	0.16	Treatment prior to transmission
	Natural Gas Pipeline	0.01	4.00	1.52	0.28		600 mile underground pipe
	Liquified Nat. Gas Tanker	7.42	5.84	0.41	0.52	2.44	63,460 dead-wt-ton tanker
	Underground Gas Storage	0.19	136.98	3.92	9.45		5000 acres; 6 x 10^{10} scf/yr capacity
	Gas-Fired Power Plant	0.79	930.00	22.40	0.03	42.90	Conventional steam plant
Solar							
	Residential Wood Stoves	32.30	134.65	29,098	28.15	565.00	Transport and flue gas emissions
	Industrial Wood-Fired Boiler	70.00	162.00	1300	325.00	79.60	Steam boiler with emission controls

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1. Compiled from The Aerospace Corp. and Mueller Associates, Inc. (1983).

Table 7. Comparison of National Emission Standards for Electricity Generating Plants. [1]

	Pollutant (tons/10^{12})		
Fuel/Country	TSP	SOx	NOx
Solid			
Australia	122		
Belgium	171		
Canada	50	299	299
Denmark	73		
Germany	24	172	386
Greece	65		
Japan	49	267	201
Netherlands	23	267	313
New Zealand	60		
Sweden	17	116	325
United Kingdom	56		
United States	15	603	302
Liquid			
Australia			
Belgium		2146	
Canada	50	299	150
Denmark	42		
Germany	21	195	194
Greece	65		
Japan	21	235	115
Netherlands			
New Zealand			
Sweden		116	
United Kingdom			
United States		394	244
Gas			
Australia			122
Belgium			
Canada	50	299	100
Denmark			
Germany	2	12	123
Greece	65		
Japan	17	191	43
Netherlands			
New Zealand			
Sweden			
United Kingdom			
United States		340	86

[1] Adapted from OECD 1984.

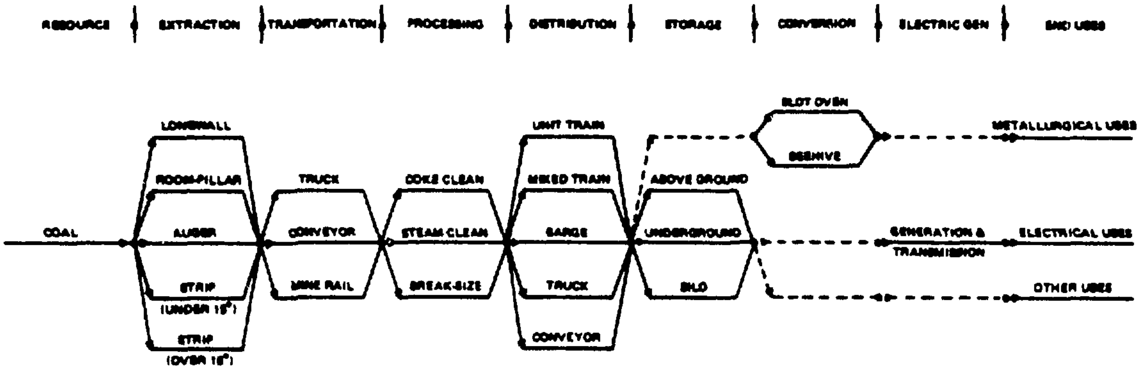

Figure 1. Energy System Network Diagram

REFERENCE MATERIAL SYSTEM NETWORK DIAGRAM

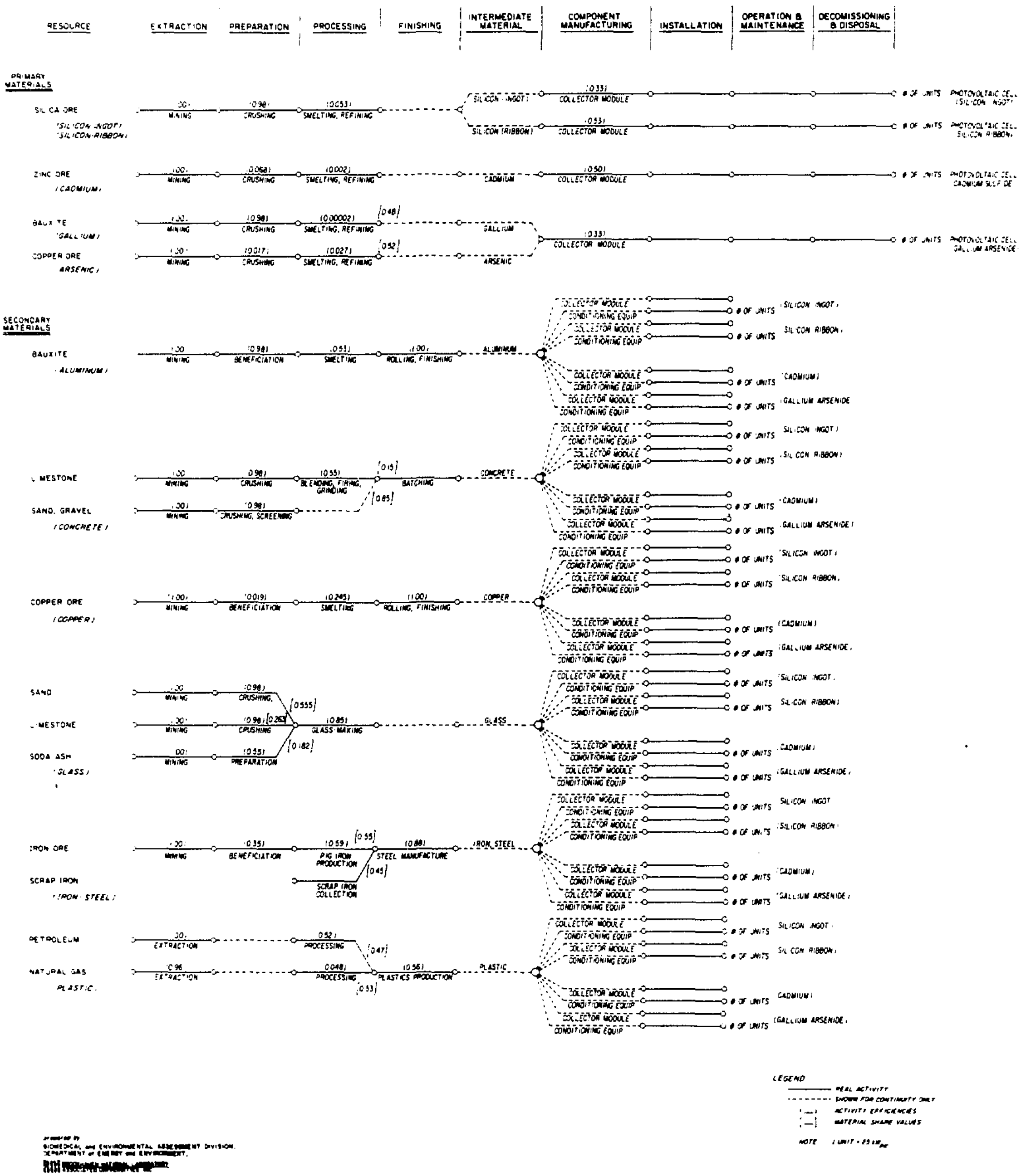

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Figure 2. Reference Material System Network Diagram