

MASTER

COMPARATIVE HEALTH AND SAFETY ASSESSMENT OF ALTERNATIVE FUTURE ELECTRICAL-GENERATION SYSTEMS

by

L.J. Habegger, J.R. Gasper, and C.D. Brown

DISCLAIMER

This report was prepared by the United States Government. It is the property of the United States Government and is loaned to you. It and its contents are not to be distributed outside your organization. The United States Government makes no warranty, expressed or implied, for the accuracy, reliability, or completeness of the information contained herein. The United States Government is not responsible for any errors or for any consequences arising from the use of the information contained herein. The United States Government is not responsible for any damage to property or for any personal injury resulting from the use of the information contained herein.

Prepared for
 IASTED ENERGY SYMPOSIA
 The International Association
 of
 Science and Technology for Development
 Montreal, Canada
 May 28-30, 1980



U of C-AUA-USDOE

RESTRICTIONS ON REPRODUCTION INDICATED
HSCW

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

**Operated under Contract W-31-109-Eng-38 for the
U. S. DEPARTMENT OF ENERGY**

COMPARATIVE HEALTH AND SAFETY ASSESSMENT OF
ALTERNATIVE FUTURE ELECTRICAL GENERATION SYSTEMS

L.J. Habegger, J.R. Gasper, C.D. Brown
Argonne National Laboratory
Argonne, IL 60439

ABSTRACT

The work report here is an analysis of health and safety risks of seven alternative electrical generation systems, all of which have potential for commercial availability in the post-2000 timeframe. The systems are compared on the basis of expected public and occupational deaths and lost workdays per year associated with 1000 MWe average unit generation. Risks and their uncertainties are estimated for all phases of the energy production cycle, including fuel and raw material extraction and processing, direct and indirect component manufacture, on-site construction, and system operation and maintenance. Also discussed is the potential significance of related major health and safety issues that remain largely unquantifiable.

INTRODUCTION

This report summarizes the results of an assessment comparing the health and safety risks of seven electricity generation technologies. The assessment was performed at Argonne National Laboratory under the auspices of the Satellite Power System (SPS) Concept Development and Evaluation Program established by the Department of Energy and the National Aeronautics and Space Administration to generate information by which a decision could be made regarding the direction of SPS after 1980. The seven technologies chosen for assessment are projected to be commercially viable within the implementation timeframe of the SPS (2000-2030). The technologies include: the SPS; a low-Btu coal gasification system with an open-cycle gas turbine combined with a steam topping cycle (CG/CC); a light water fission reactor system without fuel reprocessing (LWR); a liquid metal fast breeder fission reactor system (LMFBR); a central station terrestrial photovoltaic system (CTPV); and a first generation fusion system with magnetic confinement. For comparison with the baseload technologies, risk from a decentralized "roof-top" photovoltaic system with 6 kW peak capacity and battery storage (DTPV) was also evaluated.

Two levels of analysis are included in this assessment: the unit health and safety risks associated with 1000 MWe average generation for each technology and secondly, the cumulative risks associated with alternate scenarios of electricity supply technology mix for the years between 2000 and 2030.

METHODOLOGY

Assessing the health and safety risks of each technology required three major tasks: detailed characterization of each phase of the system as a basis for identifying the major health and safety issues associated with each of those phases; analysis of the magnitude of risk associated with each identified issue; and accumulation of risks by technology, by category of risk, and by generation scenario. Figure 1 illustrates this process and identifies the technology system activities and major sources of risk considered.

As part of the larger SPS Concept Development and Evaluation Program, detailed descriptions of alternative year 2000 baseload generation systems were compiled on a consistent basis for comparison [1,2]. For the coal system with low Btu gasification, the design was based on an SO₂ emission factor of 0.2 lb SO₂/10⁶ Btu gas, or 0.326 lb SO₂/10⁶ Btu coal. Load factors of 70% were assumed for the coal, fission, fusion, and SPS systems. Load factors for the centralized and decentralized terrestrial photovoltaic systems were 26% and 12.5%, respectively. Silicon photovoltaic cells at an array cost of \$35/m² were assigned to each of the solar systems. The decentralized solar system included 20 kWhrs of storage capacity using advanced lead-acid batteries with a 10-year lifetime. The health and safety risks of system storage or utility system back-up were not included for any of the other systems. Further details on system characterizations can be obtained from reference [1,2].

From these characterizations, and other related information, all known and potential major health and safety issues that could be unambiguously defined and discussed were identified. Each segment of the energy cycle was considered including component fabrication, plant construction, fuel extraction and processing, operation and maintenance, and waste disposal.

Compared to the more conventional coal and fission technologies, the advanced solar and fusion technologies present a tradeoff of reduced fuel requirements but higher initial capital and construction requirements. Furthermore, the industries producing the energy system components in turn require certain commodity inputs (e.g., copper mining to produce electrical equipment), and the risks associated with the production of these indirect requirements must be considered in the overall risk analysis as shown in Figure 2. Input-output tables based on the 1972 U.S. economy structure [3] were used to obtain these indirect output requirements for the various categories of industries. The associated occupational fatalities and work days lost from non-fatal accidents and diseases were then determined from historical data for each of the direct and indirect producing industry categories [4].

For risks related to remaining phases of the energy cycle, an analysis of the potential severity of the health and safety impact was completed based primarily on adaptation of available literature. (See reference [5] for full literature citation.) Whenever possible a quantitative estimate of fatalities and person days lost was made. While these measures do not define the total adverse impact of a health and safety issue, they do provide a means for comparison between technologies and categories of energy cycle activities.

A range in estimation of impact is included in each quantification reflecting the uncertainty associated with the magnitude of impact. However, for some identified potential health and safety issues it was not possible to provide any quantification. Lack of information such as dose-response relationships at low-dose levels, siting

patterns, populations exposed, uncertainties regarding probably of event occurrence, and characterizations of advanced technologies, limited estimation of risk magnitudes for some issues to qualitative discussion of potential severity or possible mechanisms for occurrence of the event.

Risk of electricity generation differs between technologies not only in the magnitude but also in the manner in which the impact is incurred. These distinctions affect societal perceptions of the acceptability of each risk and need to be preserved in the analysis. Catastrophic events constitute a prime example of the need for categorization. Because of the engineered low risk of occurrence for these events, the number of expected deaths per year, averaged over the lifetime of the plant, may be lower than that from continuous low-impact risks, but the public perception of the significance of these potential events may critically affect the viability of a technology. For this reason, plus the inherent difficulty in predicting occurrence rate and impact level, catastrophic events were not included in the quantified sum of technology risks in this study, but were included in separate semi-quantitative discussions.

RESULTS

Construction Phase Occupational Risks. For each of the energy systems considered, it was determined that for each unit value of industrial output required to directly supply system components, an additional indirect output in other industries in the range of 0.5-0.9 units is required. This significant indirect industrial output requirement similarly results in a significant addition to average unit component production impacts, as illustrated in Figure 3. The combined direct and indirect impact per unit component requirement in Figure 3 is within the same range for each technology, and as a result the total component requirement per 1000 Mwe generation is the overriding factor in determining component production risk. The total component production risks, combined with on-site construction risk are shown in Figure 4, and illustrate the higher construction phase risks of the solar technologies due to the more capital intensive nature of these technologies. This is most clearly demonstrated by the decentralized solar technologies which require a large number of small dispersed facilities to generate a total of 1000 Mwe on an average annual basis. Although not shown, similar results are obtained for the number of work days lost. For this parameter, more disaggregate data is available for risk levels for individual industry categories.

Operation and Maintenance Phase Occupational Risks. The total quantified fatality risk, averaged over an assumed 30-year lifetime, is shown for each technology in Figure 5. The operation and maintenance (O&M) quantified risks are largest for the coal technology, primarily due to accident and illness risks of coal mining. A major uncertainty in mine risk estimates derives from uncertainty in the long-term effect of recent regulations for reducing the levels of dust in coal mines. Additional occupational O&M risks are related to rail transport of coal, accidents in the coal processing and electrical generating plants, and exposure to potential carcinogenic emissions from the coal gasification process. The estimate for the latter risks from potential in-plant gasification emissions (0.0-0.2 fatalities/1000 Mwe/yr) is based on the estimated number of workers in the plant and historical data from pilot plants with limited control measures [6]. For the fission systems approximately 70-80% of the risks are related to conventional occupational hazards and the remaining 20-30% due to low-level radiation exposure, the impacts of which are very uncertain. The O&M occupational risk of the advanced fusion, SPS, and centralized terrestrial solar systems have no historical basis and are projected from conventional risk levels for existing similar occupations and estimates of number of O&M employees required [1,2]. The significant O&M occupational risks estimated for the decentralized

solar system (Figure 5) is based on 3-9 hours annual maintenance for each of the numerous small units, plus storage battery replacement every 10 years.

Operation and Maintenance Phase Public Risks. The largest O&M phase public risks quantified for this study are those related to the coal technology, and these are almost entirely due to coal transport accidents (0.8-1.9 fatalities/1000 Mwe/yr) and air pollutants (4.6-75 fatalities/1000 Mwe/yr). The estimates for air pollutant impacts includes long-range transport and the uncertainty range is based on a 60% confidence level for health effects incidence rates (adapted from ref. [7]). It should be noted that a similar procedure using 90% confidence levels gives a range including zero impacts. For the fission and fusion systems only low levels of public impacts (less than 0.1 fatality/1000 Mwe/yr) can be attributed to normal O&M, and these are primarily due to low-level radiation, which has a high uncertainty level. The quantified solar O&M public impacts are negligible.

Unquantified Health and Safety Issue. In contrast to the apparent public willingness to accept limited known risks of energy systems, recent experience with light water fission systems indicates that perceived major risks that are less quantifiable or predictable may restrict or completely halt energy system deployment if adequate assurances of very low impact probability cannot be given. For this reason potentially major, but unquantified, risks should be given prominence comparable to the quantified risks discussed above. Table 1 is a listing of potentially major unquantified issues identified for the seven technologies considered. Catastrophic events (i.e., events of low occurrence probability, but high impact per event) are included in the unquantified category because of the inherent difficulty in predicting occurrence rate and impact level. Furthermore, averaging expected catastrophic impacts over plant lifetime does not indicate the full significance of these potential events.

In general, the more defined technologies (e.g., CG/CC, LWR) have a greater number of quantifiable risks and fewer unquantifiable risks. The opposite is true for the less-defined technologies (e.g., fusion, SPS). Table 1 does not attempt to rank the unquantified issues, although, for example, potential radiation release from fission is expected to be greater than that from fusion.

Cumulative Risks From National Energy Scenarios. A further perspective on the significance of relative technology risks is provided by Figure 6, which indicates the range of annual occupational risks for 2000-2020 scenarios of energy production with and without the SPS system. A nearly constant total electrical energy capacity is assumed in this period for the scenarios (Table 2). Because of high construction and manufacture and low operation and maintenance impacts, the SPS scenario has higher initial, but lower final occupational health and safety risks, as compared to the scenario without SPS. The quantified public risks, in particular those from coal, would favor the SPS scenario with reduced conventional generation. However, the unquantified risks to the public in Table 1 restrict the delineation of definitive conclusions related to total scenario risks. A more detailed scenario analysis would also require an evaluation of the role of peaking and utility back-up requirements for the solar technologies.

CONCLUSIONS

Of the various systems considered the coal technology has the largest overall quantified risk primarily due to coal extraction, processing and transport, and air emissions, although large uncertainties remain in the actual effect of the air emission. On the other hand, additional issues that are potentially major but remain largely unquantifiable were not identified for the coal system. The decentralized photovoltaic system has large associated risks due to the large labor and material requirements of small, dispersed units. Quantified risks from the

remaining technologies (fission, fusion, SPS, and centralized terrestrial photovoltaic) are comparable within the range of quantified uncertainty. The occupational risks for component production, both direct and indirect, are a substantial fraction of the total risk, in particular for the advanced, capital-intensive solar and fusion technologies.

Of potential major significance for public acceptance of new energy systems, but not included in the quantification, is the possibility of catastrophic incidents that exist for the fission and fusion systems. Unique unquantified issues of concern also exist for the SPS in relation to the use of microwave transmission of energy and extensive space travel.

REFERENCES

- [1] M.E. Samaa, Alternative Technologies - Cost and Performance Review, DOE/NASA SPS Program Review, Lincoln, NB (April, 1980).
- [2] United Engineers and Constructors, Satellite Power System and Alternative Technology Characterization, WEAC-ANL-790831, Prepared for Argonne National Laboratory (August, 1979).
- [3] P.M. Ritz, The Input-Output Structure of the U.S. Economy, 1972, U.S. Department of Commerce, Survey of Current Business, Vol. 59, No. 2 (February, 1979).
- [4] Occupational Injuries and Illnesses in The United States by Industry, 1976, U.S. Department of Labor, Bureau of Labor Statistics, Bull. 2019 (April, 1979).
- [5] L.J. Nabegger, J.R. Gasper, C.D. Brown, Health and Safety: Preliminary Comparative Assessment of the Satellite Power System and Other Energy Alternatives, DOE/ER 0052 (January, 1980).
- [6] H.B. Ketcham, W. Norton, The Hazards to Health in The Hydrogeneration of Coal, III: The Industrial Hygiene Studies, Arch. Envr. Health, 1:194-207 (1960).
- [7] An Assessment of National Consequences of Increased Coal Utilization, Executive Summary, TID-29425 (Vol. 2) (February, 1979).

Table 1. Potentially Major Unquantified Issues Identified

<u>Solar Technologies (CTPV, DTPV, SPS)</u>	<u>Nuclear Technologies (LWR, LMFBR, Fusion)</u>
1. Exposure to Cell Production Emissions	1. System Failure with Major Public Radiation Exposure
2. Hazardous Waste From Disposal or Recycle of Cell Materials	2. Fuel Cycle Occupational Exposure to Chemically Toxic Materials
3. Chronic Low-level Microwave Exposure to Large Populations (SPS only)	3. Diversion of Fuel or By-product for Military or Subversive Uses (LWR, LMFBR only)
4. Space Vehicle Crash into Urban Area (SPS only)	4. Liquid Metal Fire (LMFBR, Fusion only)
5. Exposure to MLLV Emissions (SPS only)	
<u>Coal Technologies (CG/CC)</u>	
(None Identified)	

Table 2. Energy Scenario Baseload Capacities (GWe)

Year	LWR	CG/CC	LMFBR	SPS	Fusion	Total
2000	263	238	34	0	0	535
2020 (SPS)	188	71	78	200	11	549
2020 (w/o SPS)	213	159	140	0	37	549

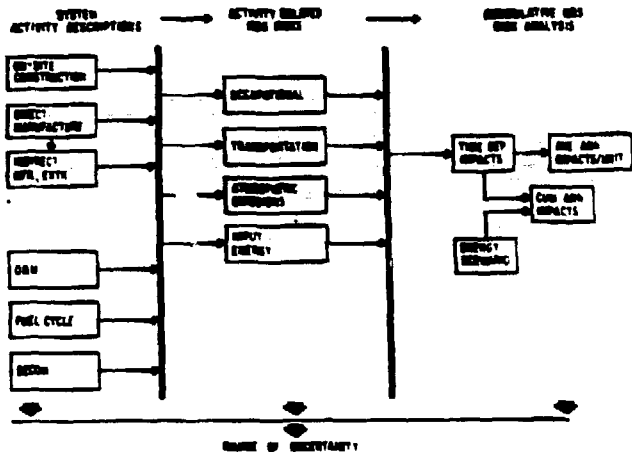


Fig. 1. Components For Comprehensive Health and Safety Impact Analysis.

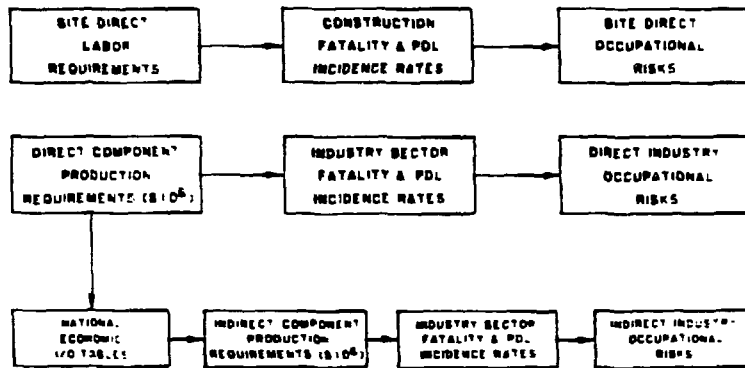


Fig. 2. Computational Procedure for Direct and Indirect Construction Occupation Impacts.

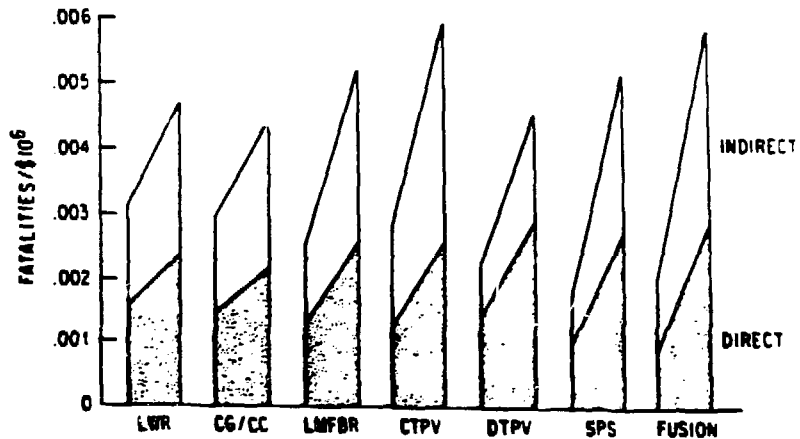


Fig. 3. Direct and Indirect Occupational Fatalities From Dair (x 10⁶) Facility Component Production.

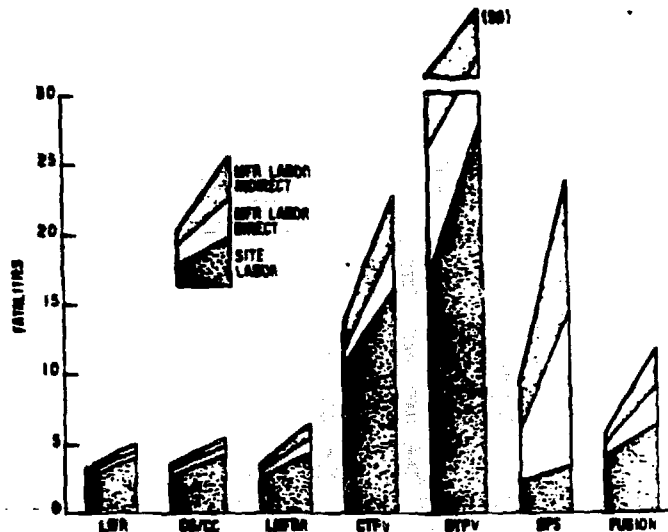


Fig. 4. Total Construction Phase Occupational Fatalities For System With 1000 MW_e Average Generation.

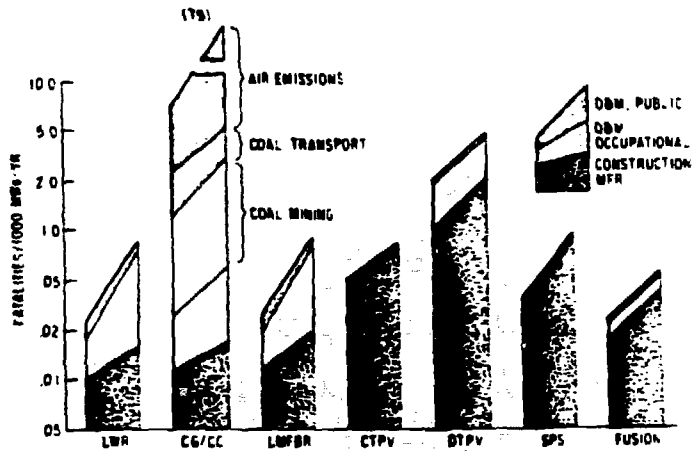


Fig. 5. Total Quantified Construction and O&M Fatalities per 1000 MW_e-yr.

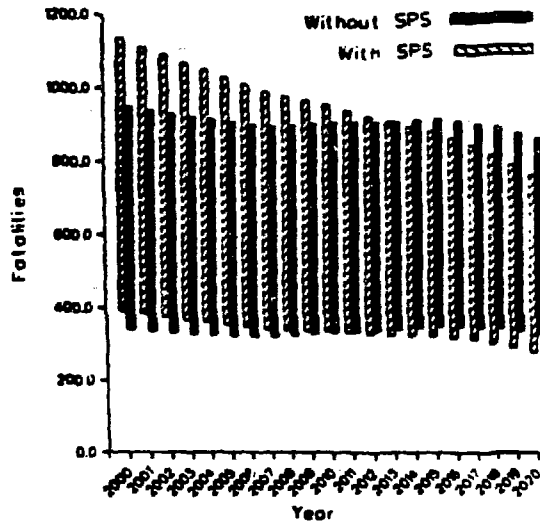


Fig. 6. Annual Construction and O&M Occupational Fatalities From Baseload Scenarios With and Without SPS.