THE ROLE OF RISK ASSESSMENT IN A POLITICAL DECISION PROCESS

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September 1981
WP-81-119

Paper presented at the
Eighth Research Conference on
Subjective Probability, Utility and Decision Making
24-28 August 1981
Budapest, Hungary

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I. INTRODUCTION

How did THAT get THERE? This is a question that might come to one's lips when driving along a beautiful section of the California coastline, spoiled, suddenly, by a number of large storage tanks. The analytically-minded person might suppose that this "place" has become a "site" only after an elaborate screening process, where careful tradeoffs have been made between the likes of "spoiling his view" and other socio-economic-technical concerns. The politically-minded person, alternatively, might wonder who had what connections at what time.

[1]The research reported in this paper is supported by the Bundesministerium fuer Forschung und Technologie, F.R.G., contract no. 321/7591/RGB 8001. While support for this work is gratefully acknowledged, the views expressed are the authors' own and are not necessarily shared by the sponsor. The author's names are listed in alphabetical order.

Though not explicitly our purpose, we shall begin this paper by contrasting these two *Weltanschaungen* of the siting problem. The analyst's single decision maker who balances the welfare and concerns of those affected by his actions does not coincide with the reality of many conflicting parties who interact in a process that resolves the large problem sequentially, where early-on decisions tend to constrain the alternatives open for the next decision, and so on. The sequential and adversary nature of the process both limits and expands the role that formal analyses can play in influencing the decision outcome.

In this paper, we will demonstrate the ways in which risk analyses have been used in a controversial siting issue, the siting of an LNG terminal in California. The conflicting and contradictory results of these studies, we will suggest, is a predictable and important element of the political debate. Not unlike many other areas of scientific investigation, it is difficult, if not impossible, to arrive at indisputable scientific truths especially where the data is scarce and subjective. Yet, because the risk studies are highly quantitative, imitating in some sense technical , engineering studies, they generate false expectations regarding the conclusiveness of the results. These studies are often seen as pursuing the truth or facts of the situation; yet, they *cannot* provide unambiguous facts. For this reason, risk analyses should be regarded as introducing necessarily ambiguous evidence into the policy process. Viewing the results of a study as "evidence" instead of "facts" offers a more realistic perspective for improving the uses of these studies, or for improving the studies themselves.

The intent of this paper is to describe the results, interpretations, and uses of three risk studies prepared during the course of the attempted siting of an LNG terminal in Oxnard, California. The decision process is briefly presented in Section II, and the three studies are described in the context of this process in Section III. In the final section, we draw some tentative conclusions regarding an improved role of technical analyses in aiding or improving siting decisions.

II. SITING AN LNG TERMINAL IN CALIFORNIA

Methane, or natural gas, becomes a liquid when cooled to -163^{o}C, with a density more than 600 times that of its gaseous phase. Liquefied natural gas (LNG) can be economically transported over long ocean distances; the economies of scale lead to large ships (e.g., 130,000 m^3 LNG) and large onshore storage tanks (e.g. 77,500 m^3 LNG each) for a base load operation such as the one proposed for California. In the event of a ship or terminal accident, a significant amount of LNG could be spilled, which would "boil off" into a methane cloud possibly covering a sizeable area before igniting and burning. Since the dispersion characteristics of methane clouds are poorly understood, there is a great deal of uncertainty involved in predicting accident consequences. Yet, the present state of knowledge indicates that at some very low probability an LNG accident could result in a cloud covering several miles before igniting. Depending on the population density of the area covered by the cloud, the possibility exists, albeit at a low probability, for a catastrophic accident.

A. THE ANALYST'S PERSPECTIVE

If a decision analyst were to observe the California LNG siting problem, (s)he could characterize it in fairly simple terms. She might view the problem as consisting of two decisions: whether or not to import LNG and if so, where to site the plant. The decision to import LNG would reduce the risk of a shortage of natural gas and improve air quality (due to an increased use of a clean-burning fuel). Yet these benefits would come at a financial cost (LNG is an expensive form of natural gas), an environmental cost (a large facility on the coast) and a cost in terms of population safety. Siting the plant at a remote and beautiful part of the coast reduces the population risk relative to siting the plant in a port, but increases environmental degradation and financial cost. As mentioned above, in the case of LNG, a great deal of uncertainty surrounds estimates of population risk. In addition, estimating the risk of a shortage in natural gas involves uncertain projections of demand and supply. In a decision-analytic sense, then, the "whether" and "where" decisions involve the trading off under uncertainty of natural gas shortage risk, air quality, environmental degradation, financial cost, and population risk.

If we examine the actual political decision process making the LNG siting decisions, it may come as no surprise that the process has very little to do with the decision-analytic framework just described.

B. A DESCRIPTION OF THE DECISION PROCESS

In the late 1960s, faced with projections of decreasing natural gas supplies and increasing need, several California gas utilities began to seek additional supplies. In 1974, Western LNG Terminal Company (Western), which was formed to represent the LNG interests of the gas utilities, applied for approval of three LNG import sites on the California coast: Point Conception, located on a remote and attractive part of the coast; Oxnard, a port city; and Los Angeles, a large harbor metropolis. The LNG would be shipped from Southern Alaska, Alaska's North Slope, and Indonesia. As of this writing, Point Conception, the one site remaining under active consideration, is still pending approval. This section describes the procedures, decisions, and events of this lengthy process (for a more complete review see Linnerooth 1980 and Lathrop 1980).

Though much preliminary work had been done by the California utilities in negotiating a contract with Indonesia and in preselecting possible sites, for our purposes the process began in 1974, when Western applied for approval of three sites: Point Conception (PC), Oxnard (OX), and Los Angeles (LA). This marked the beginning of the four-round process as shown in Table 1, where each Round can be characterized by the problem definition as perceived by most if not all of the interested parties,[2] by an event (proposal, request, etc.) initiating the discussions, and by a decision(s) or nondecision concluding the round (For a more detailed description of this characterization see Kunreuther, et al, 1981).

[2]This does not preclude the possibility that some parties might object to this definition and challenge it during the course of the debate.

Table 1. Summary of Rounds in the California LNG Siting Case

		Date
ROUND 1		
Problem Definition:	Should the proposed sites be approved? That is: Does California need LNG, and if so, which, if any, of the proposed sites is appropriate?	
Initiating Event:	Applicant files for the approval of three sites.	September 1974 (34 months)
Conclusion:	Applicant perceives that no site is approvable without a long delay.	July 1977
ROUND 2		
Problem Definition:	How should need for LNG be determined? If need is established, how should an LNG facility be sited?	
Initiating Event:	Applicant and other put pressure on the State Legislature to facilitate LNG siting.	July 1977 (2 months)
Conclusion:	A new siting process is established that assumes a need for LNG, and that is designed to accelerate LNG terminal siting.	September 1977
ROUND 3		
Problem Definition:	Which site is appropriate?	
Initiating Event:	Applicant files for approval of Point Conception site	October 1977 (10 months)
Conclusion:	Site approved conditional on consideration of additional seismic risk data	July 1978
ROUND 4		
Problem Definition:	Is Point Conception seismically safe?	
Initiating Event:	Regulatory agencies set up procedures to consider additional seismic risk data.	1980
Conclusion:	(Round still in progress)	

At the time Western submitted applications for the three sites, there existed a standard and routine process for approving industrial facilities. This siting procedure was, however, complex, involving three levels of government. The Federal Power Commission was responsible for assessing national need as well as environmental impact; the local authorities were required to grant the various licenses for land use, access, and so forth, and the California Coastal Commission (CCC) was mandated to give the final approval for any facility on the California coastline. As the application progressed through the approval channels, it became increasingly apparent that these routine procedures, especially on the local level, were ill suited to handle this large-scale facility with the potential for a catastrophic accident. The mismatch between the scale of the project and the procedures designed to approve it was aggravated by the novelty of the technology. The risks were ill defined, the experts were not in agreement on the possible consequences of a spill, and there existed no standard operating procedure and regulations.

From the point of view of formal risk assessments, the first round of the California siting process was the most interesting. To support its applications to the Federal Power Commission, Western was required to submit an analysis of the safety of the facility and its operations. For this purpose, it contracted with a consulting firm (Science Applications, Inc. (SAI)). As required by State Law, the municipalities were required to submit an Environmental Impact report (EIR); of most interest to us here was the Oxnard study which was also submitted by a consulting firm (Socio-economic Systems (SES)). Finally, the Federal Power Commission was required to carry out an in-house Environmental Impact Statement

(EIS).

Though the approval appeared to be a routine matter, the low-probability consequences of this large-scale operation complicated the process considerably, resulting in the stalemate (at last as perceived by Western) concluding Round One. The apparent significance of the risks of the planned facility appear surprising in view of the low estimates of these risks assessed by Western and the FPC. But the picture began to cloud with the discovery of an earthquake fault in the Los Angeles harbor and the publication of several worst-case scenarios for Oxnard appearing in the SES report.

Thus in 1977 Western faced a stalemate involving all three levels of government. On the federal level, the FPC was in favor of the Oxnard site, but the FPC also seemed likely to deny the Port of Los Angeles site on grounds of the recently discovered earthquake fault, though this site was favored by the local authorities. On the local level the authorities of Oxnard seemed increasingly unlikely to approve a terminal, and Western faced a complex and lengthy approval process with Santa Barbara County which held approval authority over the Point Conception site. On the state level, it seemed unlikely that the CCC, placing priority on public safety, could be convinced that an LNG terminal was safe enough for the Oxnard and Los Angeles populated areas. But the CCC also faced problems in approving the remote Point Conception site, where the marine life, kelp beds, surfing breaks and spectacular views represented the types of resources the CCC was created to protect. To complicate an already complex situation, this site was being actively opposed by the Bixby & Hollister ranch associations representing people who owned neighboring land, and by the Sierra Club, which opposed LNG on two fronts: they argued that California did not need the gas, but if it were imported the facility should be on a remote site. In summary, Western faced the possibility of not obtaining all the needed approvals for any of the three sites.

Anticipating a possible stalemate, Western turned to the California State Legislature for help, initiating Round Two of the process. Western perceived a better chance in changing the siting process in its favor than in fighting the multiple-approval, standard process. Western, supported by sympathetic interests (other utilities, business, and labor), successfully brought pressure to bear on the State Legislature to pass the 1977 California LNG Siting Act (Senate Bill 1081). This legislation concluded Round Two (see Table 1) which was effectively a problem bounding round, or a round for the purpose of narrowing the bounds of the problem to a proportion that could be handled by the relevant institutions. The act removed the decision authority from the local agencies and the CCC and vested sole state licensing authority with the California Public Utilities Commission (CPUC), a regulator with a history of sympathy for utility capacity expansion. The act also gave the CCC the role of ranking alternative sites, including the applied for site, but that ranking was not binding upon the CPUC. Finally, the act required that the site be remote and onshore.

The applicant's decision to reapply for the Point Conception site under the new process initiated the third round of political negotiations; this round was defined more narrowly than those preceding it. Essentially the only question open for the political agenda was "which site is appropriate?" While the CCC ranked Point Conception third out of its four top-ranked sites, the CPUC selected PC for conditional approval on the grounds that the higher-ranked sites would involve excessive delays as the applicant would have to draw up new plans. Again, the applicant (Western) was required to submit a risk assessment to support its application (the Arthur D. Little consulting firm was commissioned to do this study). The CPUC approval was conditional on analysis of wind and wave conditions, archeological data, and, most importantly, seismic risk. At the federal level, where both the Oxnard and Point Conception sites remained "alive", a reorganization had replaced the FPC with two agencies: the Economic Regulatory Administration (ERA) in charge of import approval, and the Federal Energy Regulatory Commission (FERC) in charge of site approval. The ERA approved the Indonesia import project. The FERC staff, which carried out detailed risk studies, favored Oxnard, but the Commissioners approved Point Conception to avoid a confrontation with the State which had legislated against the nonremote Oxnard site.

Conditional approvals on the part of the three mandated decision makers, the CPUC, the ERA, and the FERC, did not however, resolve the siting issue. Opponents of the project petitioned a Federal Appellate Court for a stay in the proceedings on the grounds that not all seismic risk evidence had been considered. The Court has remanded the case back to the FERC. That ruling, and the subsequent procedures to investigate seismic risk set up by the relevant agencies, has initiated the fourth round of discussions (see Table 1). This round is tightly defined as a technical risk issue. The single question open for discussion on the political agenda is whether Point Conception is seismically safe.

C. SITING DECISIONS AS PUBLIC POLICY

Policy analysis is often considered to be synonymous with rational decision making or problem solving. The course prescribed for the individual decision maker, that is, to identify his objectives, specify his alternatives, evaluate costs and benefits given his subjective estimates of uncertainty, and choose his preferred alternative, has been transposed to the public decision maker. This paradigm of policy as decision making or problem solving has been criticized on heuristic and institutional grounds. Majone (1981) gives three main reasons that differentiate the private from the public realm: First, in the public domain, decisions must be justified with seemingly objective arguments. Second, policies, unlike individual decisions, need to gain a consensus in order to be viable. Finally, public choices are not made by only one person. A consensus within and/or beyond an organization can be reached only with convincing and institutionally appropriate arguments.

An examination of the California siting process reveals that siting an LNG terminal is not a decision, in the decision-theoretic sense, but a public policy. As such, the political activities leading to the selection (preliminary) of Point Conception cannot be interpreted as goal-directed activities, but rather as organizational output. Organizations often deal with current issues, not so much for their sake alone, but for their longer term implications for the institutions. Western, for instance, may have pursued a change in siting procedures (S.1081), not so much because it perceived Oxnard to be blocked by local opposition, but because it recognized the longer term benefits of a one-stop licensing procedure. The California State Legislature did not set a policy for remote siting as an analyst would prescribe, that is, making explicit the tradeoffs, but compromised instead among the pro- and the anti-Oxnard interests. The Federal Energy Regulatory Commission also had to consider longer term implications of its siting policy as was evident in its strategy not to pursue its preference for Oxnard and thus provoke a Federal-State confrontation.

Another feature of the political siting process that separates it from the accepted view of rational decision making is the sequential nature of the decisions. In California, resolution of the question whether a site was needed necessarily preceded the site selection phase,[3] which in turn will precede the licensing process. Because of time and cost considerations, a decision on one level is often binding in that it cannot easily be reopened for political debate. Thus the process becomes tied or locked into certain courses of action. The responsible agencies have little alternative but to consider increasingly narrow aspects of the problem. As a case in point, during the seven-year course of the California proceedings, the need for imported natural gas in the State diminished greatly.[4] Instead of reexamining this need, the process is locked into a commitment for an import facility. Currently, all efforts are directed toward pursuing the narrower problem of seismic risk at Point Conception.

[3] In the first round, the questions of need and site were considered simultaneously. This, however, did not lead to a decision on site. In the second round, the State Legislature effectively resolved the need question.

[4] Gas prices were deregulated during this time which increased the domestic supply of natural gas.

Tempting as it may be to step backwards through the policy-decisions appearing throughout the California case in order to set out explicitly the tradeoffs made by the responsible organizations, such an exercise would only be meaningful to the extent that siting policies fit the paradigm of rational decision making. That this was not the case is evident from the sequential nature of the decisions and the operating procedures of the organizations which were concerned with a wider policy context than the Oxnard decision.

III. THE OXNARD RISK ASSESSMENTS

During the course of events in the California LNG terminal siting debate, there were seven major risk assessments carried out for the three prospective sites: Los Angeles, Oxnard and Point Conception. To understand the role these assessments played in the process, as well as in the outcome of the debate, it is instructive to review their content and use. An important point of this paper is to demonstrate that the content of such a study is largely determined by the use of the study in the political debate. It is only with an understanding of the latter that recommendations can be made for improving the former.

For the sake of brevity, and with no loss in generality, we will limit our discussion to the early studies concerning only the Oxnard site. These studies, the Science Applications, Inc., risk assessment (SAI 1975), the Federal Power Commission risk assessment (FPC 1976), and the Socio-Economic Systems risk assessment (SES 1976) will be discussed in turn.

A. AN OVERVIEW

1. Science Applications, Inc., Risk Assessment

As part of its case for the Federal Power Commission, the applicant commissioned a consulting firm, Science Applications, Inc. (SAI), to do a risk assessment of its proposed Oxnard terminal. That risk assessment was completed December 1975. It was quite elaborate, involving calculations of probabilities of vessel accidents, tank ruptures, LNG spill sizes, methane cloud dispersion and ignition, and the resulting fatalities. The computer model developed for cloud dispersion was deemed one of the two best in a Coast Guard review of several models (Havens 1977). Ship collision calculations also involved a computer model, calibrated to statistics from several harbors.

The SAI results were presented in the form of several different indices of risk. Individual annual probabilities of fatality due to the terminal were presented in the format of iso-probability contour maps of the site (see Figure 1). Those probabilities ranged from a maximum of $1.5 \cdot 10^{-7}$ near the terminal to less than 10^{-10} beyond three miles for the most conservative (risk-overstating) set of assumptions. Other contour maps were presented for less conservative assumption sets. The maximum individual probability of LNG fatality was compared to other risks: The individual probability of dying in a fire generally was reported as 220 times greater; the maximum probability of having a plane fall on a person in the site vicinity was reported as 10 times greater than the LNG risk. Annual probabilities of catastrophes were also presented, including 10^{-8} for a 2,000 to 10,000 fatality year, and $1.4 \cdot 10^{-57}$, or "one chance in 710

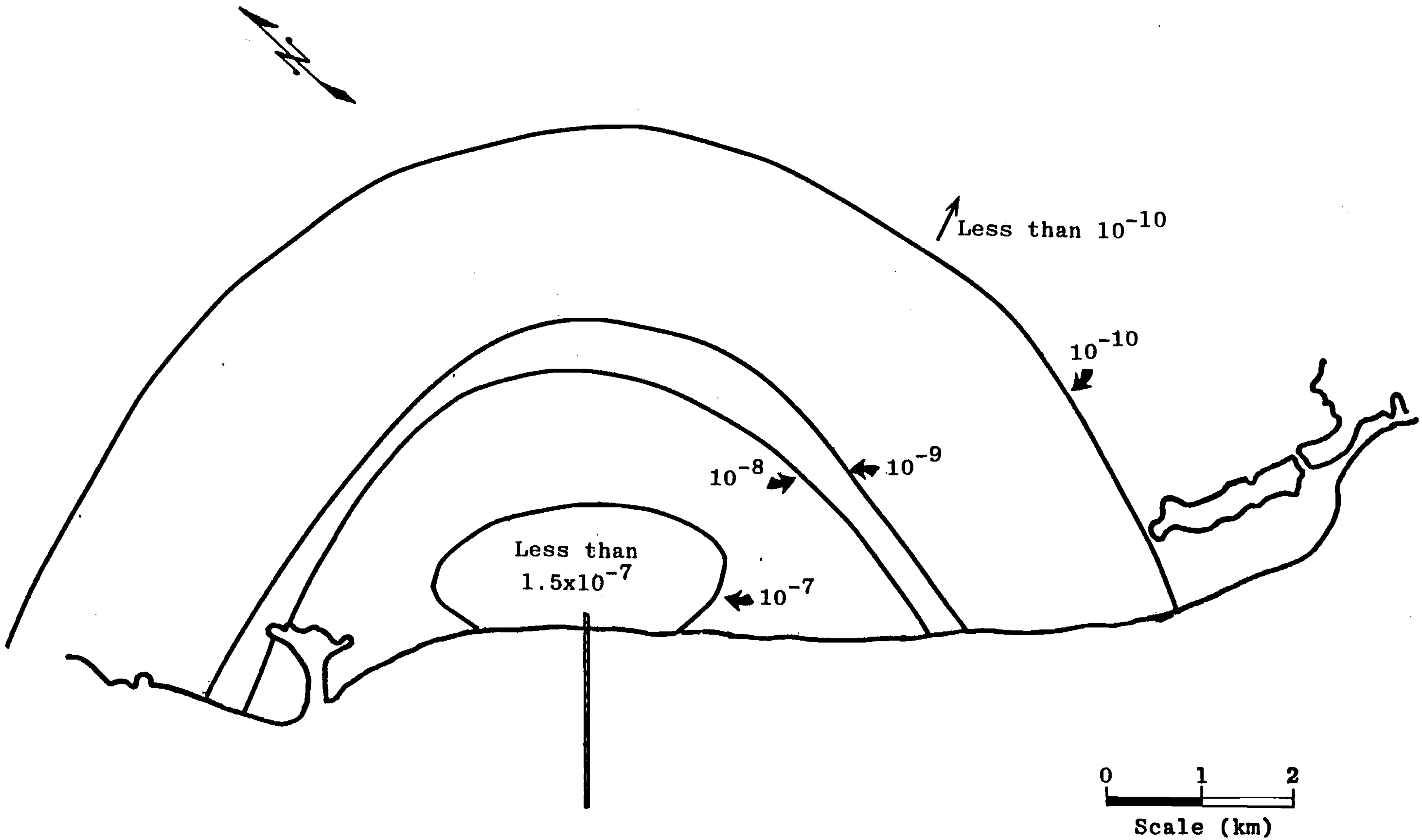

Figure 1. Iso-probability contour map for Oxnard, most conservative assumptions.
Source: SAI (1975)

septendecillion," for the maximum catastrophe: 113,000 fatalities. For comparative purposes, another study was cited that gave the probability of a 32,000-fatality plane crash (into a race track) as 10^{-10}, five times greater than the probability of 2,000 to 10,000 LNG fatalities (for a different set of assumptions than that used to get the 10^{-8} number above). The study concluded that LNG risks at the Oxnard site were "extremely low."

The results of the SAI study seem to have been accepted and interpreted as intended in the FPC hearing. The FPC decision of July, 1977, cited all the various numbers mentioned above and a few more, noted the conservative assumptions, pointed out that no party disputed the findings, and found that the Oxnard site involved levels of risk sufficiently low for FPC approval. However, this decision had no bearing on the siting process, as shortly thereafter a federal reorganization abolished the FPC and set up a new approval procedure.

2. Federal Power Commission Staff Risk Assessment

The staff of the FPC also performed a risk assessment as part of the Environmental Impact Statement (EIS) to be presented to the Commission in the July, 1977, hearing. The assessment was completed in November, 1976. This assessment generally used less elaborate models and less resources than SAI in reaching its conclusions. The logic of the report can be stated quite simply: All significant risks were seen as arising from ship accidents. While that is plausible for technical reasons, the assessment did not defend that assumption with analysis. Those accidents were assumed to happen at last as far from shore as the end of the 6000 ft (1.8km) trestle of the Oxnard facility. Since the FPC staff determined that the maximum travel of the flammable vapor cloud and maximum distance of significant fire radiation effects were both less than 6000 feet, the risk was deemed to be "negligible."

The FPC assessment results included risk measures for the Point Conception and Los Angeles sites. In all three cases, risk was measured by two indices: annual expected fatalities and annual individual probability of LNG fatality. However, for the reasons discussed above no numbers were given for those indices for Oxnard, only the abbreviation for "negligible". The report concluded that ship transport to the Oxnard site "constitute[s] an acceptable risk to the public."

As with the SAI study, the results of the FPC staff assessment seem to have been accepted at the FPC hearing. The decision of July, 1977, cites both the FPC and SAI results in support of its conclusions already discussed.

3. Socio- Economic Systems Risk Assessment

As part of its Environmental Impact Report process, the city of Oxnard commissioned a consulting firm, Socio-Economic Systems, Inc. (SES), to do a risk assessment of the LNG terminal. That assessment was completed in September 1976. It took a much broader look at the problem than the previous two assessments. Rather than characterize the risk solely in probabilistic terms, the report presented 26 "population risk scenarios," with maps of the Oxnard area with shaded maximum plume areas or fire radiation zones superimposed, for each of several wind directions, spill sizes, etc. (see Figure 2). Each scenario named a "population risk," in fact the number of people covered by the maximum plume or fire zone, which ranged from 0 to 70,000. These scenarios could be described (though SES did not) as maximum credible accidents. They were not accompanied by any estimates of their probabilities, though those would have to be quite low for the large fatality scenarios for technical reasons.

In the section immediately following the scenarios, the SES report presented a more probabilistic analysis, which in fact combined numbers and assumptions from the SAI and FPC studies and a Coast Guard study. It basically combined the most conservative assumptions and numbers of each of the studies. In tabulating these, the report pointed out wide differences in numbers used in different studies. For example, the FPC used a probability of ship collision more than 5600 times larger than the one used by SAI. The number of expected fatalities per year computed in this way was 5.74, or 380 times larger than the SAI estimate. These numbers (SES and SAI estimates) were compared with expected fatalities from other hazards. While by the SAI estimate LNG has 7 times more expected fatalities than a hypothetical Oxnard nuclear plant, by the SES estimate LNG has 2900 times more expected fatalities.

The SES report also plotted annual probabilities of catastrophes against the numbers of fatalities involved, for the SAI and SES estimates, and other hazards for comparison (see Figure 3). Once again, the SAI estimates for LNG were higher than the numbers for a nuclear plant, while the SES estimates were much higher still. The SES report also

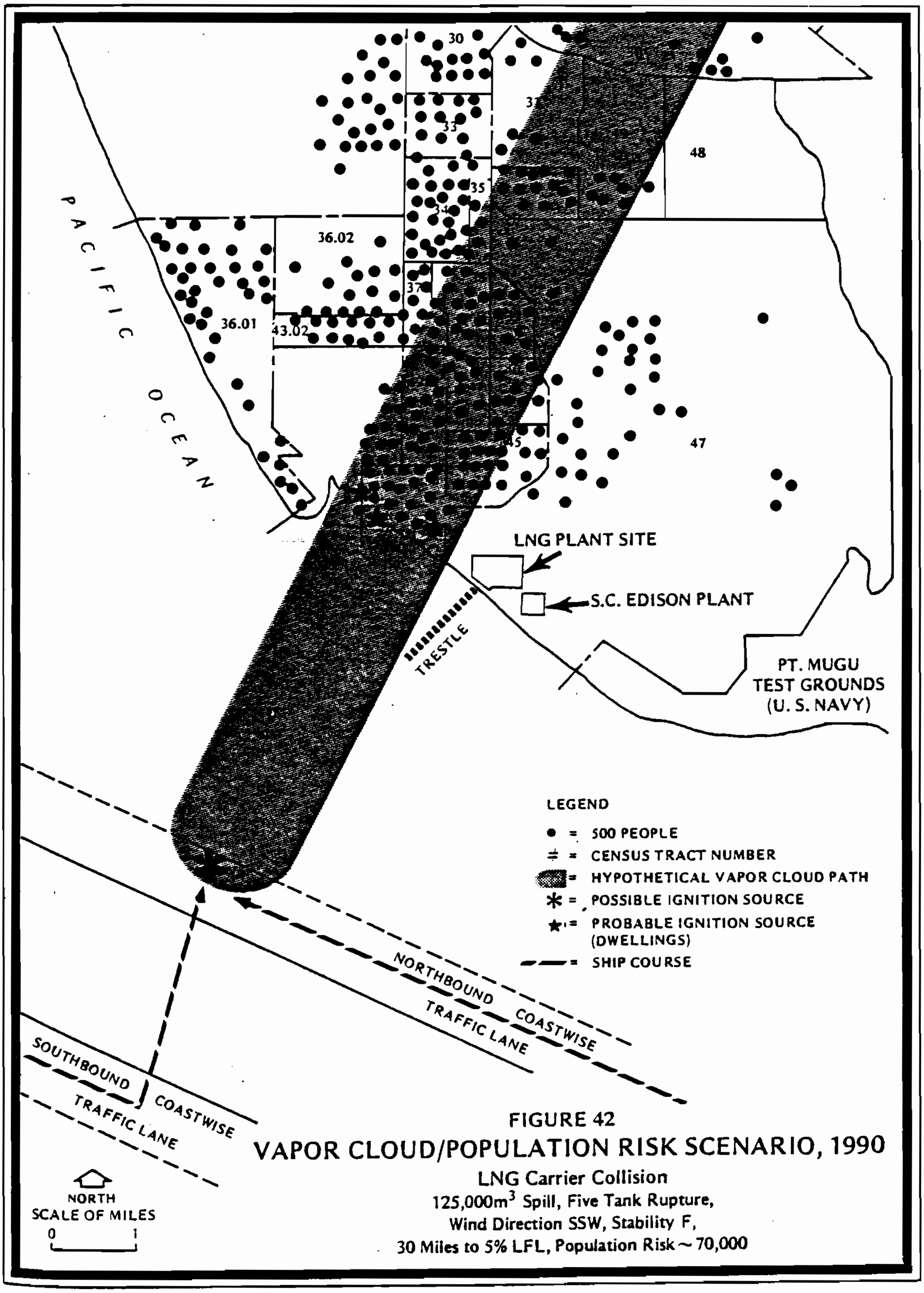

Figure 2. SES population risk scenario for Oxnard. Source: SES (1976).

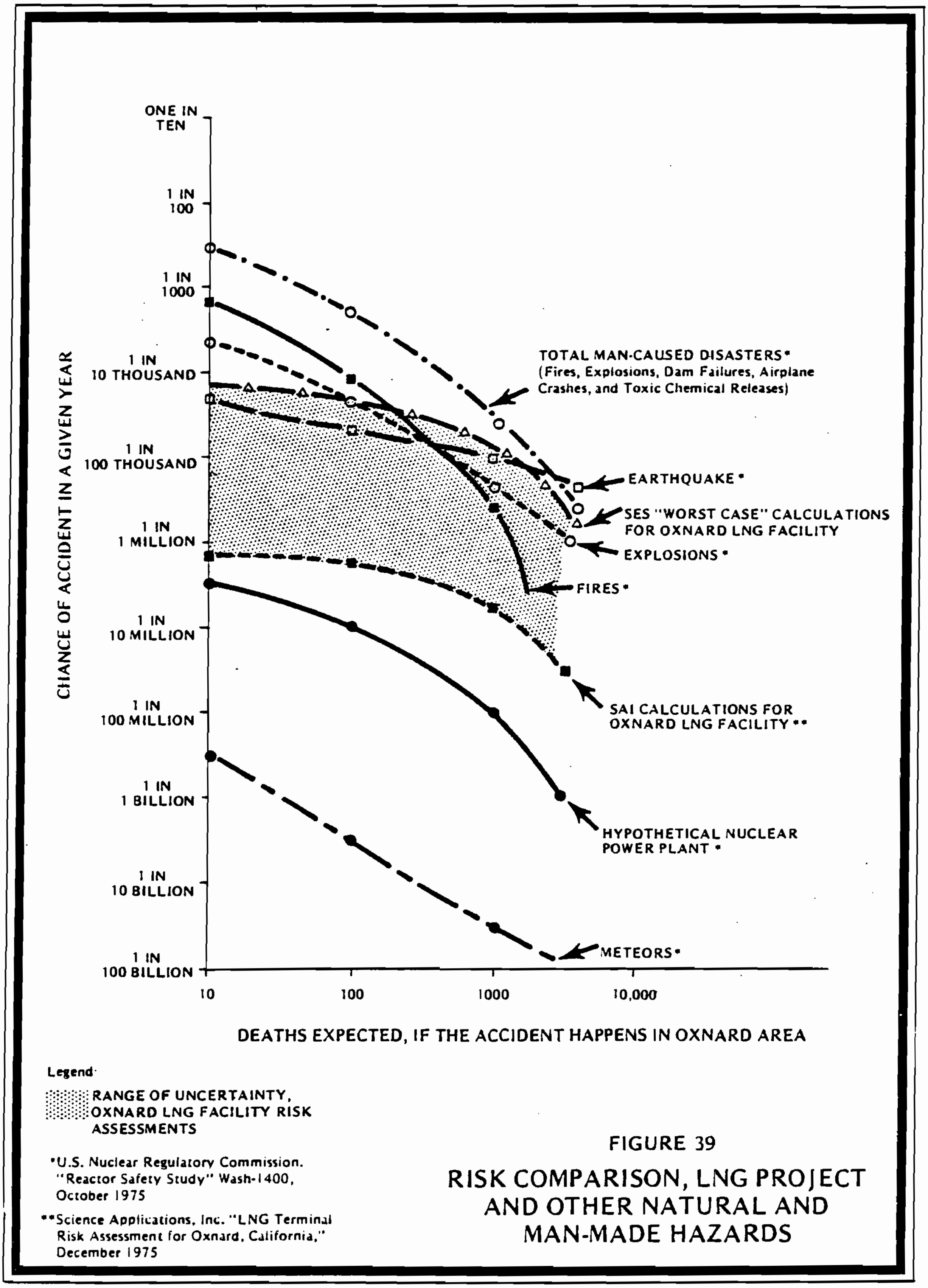

Figure 3. Probabilities vs size of catastrophes.
Source: SES (1976)

included several estimates of risk to property. In marked contrast to the other two assessments, the SES study concluded that in view of the problems of estimating risks with very little experience base, the differences in risk estimates between reports, and various other problems, "it is not now possible to state confidently that the proposed facility poses a 'low probability' of a high consequence accident."

As it happened, the SES report was never used in an official decision process, because the California LNG siting process was changed by new legislation in 1977, which ruled out non-remote sites such as Oxnard. However, the SES report may have been quite influential in unofficial ways. The population risk scenarios, which allowed local residents to see some deadly methane plume covering their own homes, in Ahern's (1980) words "electrified opposition to the terminal." In addition, the generally cautious tone of the report may have increased the sense of caution and dampened support for the terminal in the city council. The report seems to have generally increased opposition to the terminal, opposition which led eventually to the remote siting provision of the 1977 siting legislation. As late as 1980 one of the authors was told by a state legislative aid that the state could not site a plant that could kill 40,000 people. The 40,000 fatalities matches the format of the SES report.

B. COMPARING THE ASSESSMENTS

Now that each of the three risk assessments has been described, key features of each assessment can be selected for comparison. Table 2 brings together a set of comparisons in summary form. Each comparison is discussed in turn here.

1. Role

As indicated in Table 2, each assessment filled a different role in the siting process. In the case of the SAI study, it seems clear that the role of the assessment was to defend the application. In the other two cases, the assessments could be seen as having advisory roles: the FPC study was done by the staff to advise the commissioners, and the SES study was part of an environmental impact report (EIR) process, where the goal was to provide a data base for all parties to the process. Yet in each case the analysis process itself is not observable, only the reports. The reports were written after the analysts had developed a particular stand, which was then supported by the reports. In all three cases, then, the report was written to persuade some party or parties of a particular stand. This phenomenon is discussed in more detail in later sections.

Table 2. Summary comparison of risk assessments.

Assessor	SAI	FPC Staff	SES
Role:	support applicant stand to regulator	support staff stand to commission	support SES stand to all parties
Scope:	thorough, but own models only	only ship accidents at end of trestle	composite of several studies
Example Parameters:[1]			
probability of ship accident	$5.6 \cdot 10^{-6}$	$3 \cdot 10^{-2}$	$3 \cdot 10^{-2}$
cloud distance, $25{,}000m^3$	2km	1.2km	23km
Example Results:[1]			
maximum individual probability (p_i)	$1.5 \cdot 10^{-7}$	"negligible"	--
catastrophe size: prob.	2,000-10,000: 10^{-8} 113,000: 10^{-57}	-- --	4,000: $2 \cdot 10^{-6}$ (note 2)
expected fatalities	.015	"negligible"	5.74
Formats: (besides tables)	iso-p_i contour maps (see Figure 1)	--	1) max plume maps (see Figure 2) 2) catastrophe size vs probability, (comparative) (see Figure 3)
Conclusion:	" ... risks ... are extremely low."	"... risks ... are ... negligible." "...an acceptable risk to the public."	"...it is not now possible to state confidently that (it) poses a 'low probability' of a high-consequence accident."
Effect:	FPC persuaded to approve	FPC persuaded to approve	increased opposition decreased support

[1] Several differing qualifying conditions apply to each number, so data is only appropriate for very rough comparisons. All probabilities and expected values are annual.

[2] This figure was scaled off of a low-resolution figure, and so is quite approximate.

2. Scope

Each assessment adopted a very different scope of consideration, which explains many of the fundamental differences in the results and effects of the assessments. The SAI report was quite thorough, but used primarily in-house computer models for the important calculations concerning ship accidents and flammable cloud travel distances. While those models were quite impressive, by neglecting to acknowledge the existence of experts and models with conflicting results, the SAI report over-stated the confidence with which the results should be accepted. The FPC report considered only one type of accident: ship accidents at the end of the trestle. There were reasons for believing that other accidents would not add significantly to the risk. However, because the staff did not carry out calculations to prove that contention, that important narrowing of the problem is defended only by the analysts' judgment. Other parties to the process are then apt to suspect that the risk is under-stated. The SES study combined widely varying results of several other studies. In doing so, the analysts were able to make abundantly clear the extent of uncertainty in expert opinions on LNG safety.

3. Parameters

Table 2 presents important parameters used in the risk calculations of each of the studies. As can be seen from the table, those parameters differed by from one to four orders of magnitude between the assessments. This makes clear the large uncertainties in elements of the assessments, uncertainties which contributed to the widely differing conclusions and effects of the assessments. Clearly, such uncertainties should be reflected in the assessment results. Yet the SAI report did not discuss them, and while the FPC report acknowledged them, they were not presented as qualifying factors for the results. (A later report on Oxnard by the Federal Energy Regulatory Commission, successor to the FPC, took some of the uncertainties into account.) If each risk assessment was in fact a probabilistic representation of the available technical knowledge concerning LNG risk, as may have reasonably been assumed by any reader, then each assessment should have acknowledged the existence of conflicting opinions about physical processes important to LNG risk. This is an especially important matter for low-probability catastrophic risks such as LNG, since the very low reported probabilities of catastrophe could be meaningless given conflicting expert opinions. For example, how meaningful is a probability of 10^{-57} of a catastrophe if there is a probability of 10^{-2} that the cloud dispersion model on which that 10^{-57} was based is seriously in error? (See Mandl and Lathrop 1981.)

4. Results and Formats

Several conclusions can be drawn from an examination of the results and formats sections of Table 2. Not only do the assessments differ by up to two orders of magnitude on the measurements of risk, they differ more fundamentally on how risk is characterized: what dimensions are used to describe risk and what formats are used to present the results. The maximum plume maps of the SES report, essentially maximum credible accidents very vividly described, "electrified opposition to the terminal," to quote Ahern (1980). Other dimensions and formats seemed to have an opposite effect. Underlying this problem is the fact that there is no objective "risk" associated with any physical plant. Beyond the problems of having to use subjective probabilities where no frequentistic data base is available, risk itself is a many-dimensioned concept, with no apparent consensus on how those dimensions should be combined into a risk measure. There is an odd lack of precision in many risk assessments as to just what it is that is being assessed. A survey of 18 risk assessments found that only 4 of them included an explicit definition of risk, and those 4 were quite different (Mandl and Lathrop 1981). In one of those 4 assessments, several measures of risk were presented that had nothing to do with the announced definition. It seems to be the case that risk assessments are commissioned without any specification of what it is that is to be assessed. Operating in that odd vacuum, each risk assessment team sets out to characterize risk in whatever way it sees fit.

But even when risk assessments of the same physical plant are compared on the same measure, large differences are found. One example is the annual expected fatalities for the Oxnard facility. The SAI assessment yielded .015; the SES assessment yielded 5.74, or 380 times the SAI number (which makes one wonder about the two and three significant figures of the assessments). The basic cause of this lack of agreement is that these allegedly probabilistic assessments in fact are not completely probabilistic. In each case, gaps in the probabilistic models are filled by assumptions that often are not probabilistic or certainty-equivalent representations of incomplete knowledge. One example is the probability of ignition at the spill site, given an LNG ship collision. That number was not produced by a computer model, but was simply set by direct judgment. In those cases the number selected was not some expected value, modal value, or certainty equivalent, but was typically a conservative value, i.e., a number that would overstate the risk with some unstated confidence. The idea behind this is that such an assessment is more defensible: the final measure is not apt to understate the risk, since all gaps in the model were filled by risk-overstating numbers. Yet then the "expected fatalities" measure is not expected fatalities, but some odd mix of maximum and expected fatalities.

This conservatism has two important effects. First, it contributes to differences between assessments, since there is a wide range on just how conservative each assumption is. The SES study simply compared SAI, FPC, and U.S. Coast Guard studies and adopted the most conservative assumptions from each to reach its 5.74 expected fatalities, 380 times the SAI estimate. Second, conservatism blurs the distinction between probabilistic and non-probabilistic measures. The population risk scenarios of the SES study, very similar to maximum credible accidents, seem very non-probabilistic. Yet each one was generated simply by making many conservative assumptions, so they are not in fact qualitatively different from the expected fatality measures, which were also generated by making conservative assumptions.

5. Conclusions

One of the most striking contrasts between the assessments is found by comparing their verbal conclusions, as summarized in Table 2. It is hard to believe that the SES study is describing the same site and technology as the SAI and FPC studies. Yet with the exception of the FPC "acceptable risk" statement, in some sense every conclusion in Table 2 is correct and even consistent with each other. The SAI and FPC statements were prefaced by "it is the opinion of ... that ..." phrases, with no descriptions of how confident the analysts were of the results, and so they do not conflict with the SES "not ... possible to state confidently ..." phrase. But of course, confidence in results is an essential issue here, as has been discussed in preceding paragraphs.

The "acceptable risk" opinion of the FPC staff raises the issue of how broad the mandate of the risk assessors should be. The other assessments only comment on the level of risk, not its acceptability. Several authors have made the point that the acceptability of a risk is an essentially political question, beyond the legitimate mandate of technical risk assessors (see e.g. Fischhoff, et. al. 1980).

6. Effect

As indicated in Table 2, there were two markedly different effects produced by the three assessments. It is possible that the SES study produced its negative effect because of its larger measures of risk. However, according to a key participant in the process (Ahern 1980), the important differences were the maximum plume map formats used by SES and the great deal of uncertainty acknowledged in the SES conclusions.

7. Other Factors

Perhaps one of the most important factors in all three of the risk assessments is the highly conditional nature of the results. Yet this factor is not clearly presented as a qualifier in any of the assessment conclusions. For example, none of the assessments take sabotage or terrorist action into account. According to the FPC decision, SAI maintained that such risks cannot be quantified. Yet the appropriate response to that problem is either to use direct subjective judgment (as was used for ignition probabilities) or to make very clear in the presentation of results that such events are omitted. To do neither has the effect of understating the actual risks, in curious contrast to the conservatism discussed earlier.

8. In Sum

In reviewing the differences among the assessments just discussed, it becomes clear that there is a great deal of leeway, or degrees of freedom, left to engineering and analytic judgment. Among those degrees of freedom: decisions concerning how to characterize risk, what formats to use for presentation, what gaps to fill with assumptions of what degree of conservatism, which of several conflicting models to use, how to portray the degree of confidence in the results, and what contingencies simply to leave out of the analysis. This leeway explains the differences among the three risk assessments examined here. It can push the risk measurement results in any direction. Very conservative assumptions can drive it up; omissions of inconvenient aspects such as terrorism can drive it down; clear presentations of expert disagreements can decrease the confidence in the results; particular formats can feature more or less salient aspects of the risk; and so on. The degrees of freedom left to the analyst can have a major effect on the results of the analysis, over- or under-stating the risk over such a large range that the final result may have more to do with the predilections of the analyst than with any physical characteristics of the site or technology. Such a great deal of leeway can cause problems in the use of risk assessments in societal risk management debates. While some such analytic freedom is desirable and perhaps necessary, risk debates could be clarified considerably by analytic standards, or "rules of evidence", as will be discussed in the last section.

C. POLICY CONTEXT

In this section, we would like to turn to examining the assessments within the context of the policy process. Particularly, we will describe the *timing* of the assessments in relation to how the problems were defined on the political agenda, the *purpose* of the assessments in relation to these problems, and the *uses* of the assessments. In the following section, we will reexamine the content of the reports from the perspective of their role in the policy process.

1. Timing of the Risk Assessments

The Oxnard risk assessments examined here were carried out in an early stage of the process. The problem (Round One) was defined in vague terms. Both questions, whether an LNG terminal is needed and which, if any, of the proposed sites is acceptable, were yet to be resolved. The process, not locked into having a terminal or necessarily approving any of the sites, did not have a clearly defined direction. Many possible issues could have served as a focus or "handle" for the arguments, pro and con, any site. Since the assessments were commissioned during this unstructured and vague stage of the debate, it is not surprising that "risk" became an important focus for the discussions.

The significance of the timing of these studies is especially clear when viewed in a cross-national context. In the FRG, for example, the risks to the surrounding population from a proposed LNG terminal were first considered after the site, but before the design of the terminal, had been approved (Atz 1981). In the UK, a risk assessment will be carried out for an export terminal planned in Scotland only after the terminal has been built (Macgill 1981). It is not surprising that the safety of the plant has played a larger role in the U.S. than in the FRG and the UK.

2. Purpose of the Risk Assessments

A general purpose of each of the assessments was to establish the acceptability or nonacceptability of the Oxnard terminal from the standpoint of the safety risks it would impose on the surrounding population. From an analyst's point of view, it is striking that the question of safety was not viewed in terms of the benefits of the facility (cost-benefit framework) or in terms of the safety of alternative energy sources. This threshold concept of safety (is it safe enough irrespective of benefits or alternatives?) is typical of debates on the assessment of new and novel technologies, and is not surprising when seen in relation to the political decision procedures. The assessments were *not* made as an input to a wholistic analysis, such as that described in Section II, where tradeoffs are explicit, and all alternatives are evaluated, but rather as support for an argument supporting or opposing less significant, incremental decisions at a particular point in time. The sequential nature of the decision procedures, as clearly demonstrated by the increasing concreteness of the problem definitions through the four rounds of discussions in California, limits the possibilities for comprehensive analyses. The risk studies were carried out, not as an input to a broad energy siting analysis in California, but to support a more narrowly defined problem (Should site x or site y be approved?). Since Round One in California was *not* defined in these narrow terms (the question of whether the terminal was needed was yet to be resolved), the analyses were ill suited to address fully the issues on the table. In some sense, then, analyses designed to address the question of safety were prematurely introduced into a process that had not resolved higher-order questions of energy policy. Though they served to focus the debate on the safety question, they could not offer (nor were they intended to offer) a panacea for the resolution of the siting question.

It is not surprising, then, that Round One ended in a stalemate. The second round, where the State Legislature took center stage, narrowed the problem (by resolving the question whether California needed a site) to a proportion more receptive of technical risk studies.

3. The Uses Made of the Risk Assessments

Attempting a taxonomy of technical risk analyses, it might be useful to distinguish between those commissioned (or carried out in-house) to advise the client (or advise the agency) on a course of action (pre-decision) and those commissioned to support or rationalize a client's actions or intended actions (post-decision). The latter should not be viewed as falling outside the legitimate business of policy analysis. As Majone (1981) points out, "the policy-making process is driven by the clash of opposing arguments and for this reason policy makers need retrospective (post-decision) analysis, including 'rationalization' as much as they need prospective (or predecision) analysis" (p.17). Though the pre- and post-decision distinction is useful, the distinction was not always in the case of Oxnard a clear one. The reason is that there were, as would be expected, several audiences over time, for each of the three studies.

The SAI study, as commissioned by Western, can be fairly unambiguously classified as a post-decision rationalization; the expressed purpose was to defend Western's decision to site at Oxnard at hearings held on the question by the FPC, which was in charge of approving the application. The SES report, alternatively, was commissioned for the purpose of advising the Oxnard City Council of the accident risks for the Oxnard site. As could have been anticipated, its audience expanded in time to include local interest groups, the Sierra Club, and eventually the State Legislature, and the purpose of the report was transformed from advising to rationalizing arguments against Oxnard as a suitable site. The case of the FPC is the most ambiguous. Though the report was prepared to advise the staff in taking a position on Oxnard, it was carried out in full knowledge that it would be used to rationalize the staff's chosen position at the Commission hearings.

An important point here is that all of the analyses were used, if not immediately, at some time to support a stand taken by one or more of the parties. Their functions were not in any case limited to that of solely advisory. Each was intended to go beyond that of planning a course of action (or stand) on the part of the client to that of defending the client's position in a public setting (usually a legalistic hearing). For this reason, there was an important and legitimate--within the policy context--element of persuasion associated with each report.

D. THE ROLE OF RISK ASSESSMENTS

The role of risk assessments can be viewed from two opposing perspectives. On the one hand, they are seen as quantitative and therefore in some sense, objective, or imitating the physical sciences. On the other hand, as pointed out in Section B, the large uncertainties involved necessarily push the evidence out of the realm of "facts" and into the realm of "opinion." This dual nature of a formal risk study has often fogged discussions on their role in the policy process.

1. Facts vs. Judgment

The possibility that the form or content of scientific knowledge, as distinct from its incidence or reception, might in some way be *socially determined*, has recently been put forth by sociologists of science. Indeed, the sociology of science as developed in Europe since the early 1970s has challenged the positivist view of science (for a review of this literature, see Mulkay [1980]). Though several authors have discussed the possible "pitfalls" of analysis, whereby values on the part of the analyst color his "methodologies" and results and whereby heuristics introduce biases into his work, Wynne (1981) reminds us of the importance of recognizing these biases as part and parcel of science and not eradicable lapses from proper rational scientific analysis.

> There is a pervasive myth about the nature of science which supports this false approach to the question of "analytic bias." The tendency in the literature is to regard bias or mistakes as individual and isolated in origin, which suggests that ideal objective scientific knowledge can be attained in professional practice and as an input to policy issues.... This gives a fundamentally misleading and politically damaging picture of the role of expertise, and may make us part of the problems we analyze (pp.1-2).

A recognition of the inevitability of intertwining facts and values leads us to examine critically recent notions of the desirability of separating information from judgment. The widely-held view of the scientist producing "objective" information and keeping "facts" and "values" in separate, airtight containers, clearly reflects the acceptance of the "standard view", of science. An opposing view, as suggested in the above quote by Wynne, is to recognize that there is an important element of subjective judgment in all scientific experiments, which is especially apparent in policy analysis. There is a clear need for judgment in all steps of an analysis: (a) setting or defining the problem; (b) collecting the data; (c) choosing the tools and methods of analysis; (d) presenting the evidence and formulating the arguments; and (e) drawing conclusions, communicating and implementing the results. As has been argued by Ravetz (1971) and Majone (1980), policy analysis is the work of a craftsman.

Seen in this light, it would be naive to suppose that a level of risk can be estimated and accepted as fact. Scientific truths are not proved but are the product of a process of general acceptance in the scientific community. Since rational methods for discovering the scientific information to guide policy are often inconclusive, Majone (1981) points out that often non-rational (not to be confused with irrational) methods are used, including bargaining, voting, delegation, material incentives, and procedures. Majone suggests further than *persuasion* is perhaps the most important of these non-rational methods. Though analysts raised in the tradition of the standard view might view persuasion as illegitimate or as violating the central values of scientific methods--objectivity and rationality--there are, according to Majone, "reasonably well-defined situations in which persuasion can be, and has been, used legitimately in support of rational analysis " (p.17).

2. The Advocacy Role of Risk Assessments

A review of the three Oxnard risk assessments has revealed striking differences in their "scientific" content: the relative conservativeness of the assumptions, the completeness of the analysis, the characterization of safety or "risk", and the formats for presenting the results. A review of the policy process has revealed that the assessments were done to persuade either the client (advisory role) or a decision-making body (rationalization) of the safety or nonsafety of the Oxnard terminal. The SAI study was intended to rationalize to the FPC Western's choice of Oxnard; the FPC study was intended to advise the FPC staff and then to persuade the commissioners of the merits of the staff's position; the SES study was intended to persuade the client, the Oxnard City Council, of the analyst's own reservations of the safety of the Oxnard terminal.

It is clear from the nature of the problem, indeed from policy analysis in general (and maybe all "scientific" investigations), that there are many competent and respectable ways of analyzing the problem. No one set of assumptions is best; no analysis can be complete, no assessments are "free" of judgment. In fact, the assessments express opinion, an opinion in support or rejection of a policy argument. As in any area of uncertainty, it would be expected that there is a range of judgment opinions. It would also be expected that these opinions in support of arguments are expressed as persuasively as possible.

Seen in this light, it is not surprising that SAI found the risks of Oxnard to be "extremely low"; that the FPC found those risks to be "negligible," and that SES, having concluded that there are large uncertainties involved, presented some of their results in the form of worst-case scenarios. These were all legitimate persuasive forms of presentation when viewed in the context of the adversary process.

Yet, in many ways there is room for improving the analyses. There are clear merits in having uniform assumptions, more complete analyses, and broader characterizations of the risk problem. But reforms in the content of the analyses cannot be made independently of the process in which the analyses are commissioned, carried out, and used. Broad and useful studies will only be carried out within a political process that encourages and rewards them.

IV. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

In this paper we have examined the role risk assessment played in a political decision process: the siting of an LNG facility on the California coast. From an analytic perspective the siting problem is one of trading off several objectives under uncertainty: environmental quality, cost, gas supply interruption risk, and population risk. Yet the political decision process bears no resemblance to such a rational structure: several interested parties with conflicting goals and different short- and long-term agendas come together in a series of structured and unstructured debates. That set of debates generates a sequential decision process, where bounds on the overall siting problem are successively narrowed as parts of the problem are resolved.

We examined and compared three risk assessments that were produced in the course of the California LNG siting process. That comparison established that many degrees of freedom in a risk assessment are left to the analysts' judgment. Those factors can affect the results of the assessment in major ways, determining the level of risk measured within a very broad range (perhaps two orders of magnitude), the degree of confidence ascribed to the results, and the salience of the risk. As a consequence, the results of a risk assessment may be determined as much by the judgments of the analysts as they are by the site and technology considered.

But risk assessments should not be considered as analyses existing in a vacuum. An understanding of the political context within which the assessments operate is vital to the development of improvements in those assessments. The purpose of a risk assessment in the political process we studied was *not* to assess risk, but to support one side or another in debates concerning the acceptability of a risk, where those debates affected incremental decisions in a sequential process. That means that the timing of a risk assessment can be crucial to its nature and effectiveness, and that its effectiveness is a function not of analytic rigor, but of its persuasiveness.

From some normative point of view, the ideal role of a risk assessment is to make such technical information as can be mustered available to the political decision process in such a way that the information is effectively used. Yet our comparison of risk assessments found that the assessment results depended as much on analysts' judgments and presentation formats as they did on technical aspects of the site and technology. Our examination of the role actually played by the assessments found that they were designed more to persuade than to inform. Given these realities of the political process, then, it seems that risk assessments should be treated in the same way as other more obviously subjective evidence in hearings and procedures. It follows that a promising strategy for improving risk assessments would lie in the development of "rules of evidence", standards that assessments must meet in order to be used in a hearing or accepted as part of an environmental impact report. The next section outlines desirable features of those rules, and suggests an initial set of rules to be considered for further development.

B. A SUGGESTION FOR IMPROVING RISK ASSESSMENTS: RULES OF EVIDENCE

1. Desirable Features

Consider first a risk assessment as single entity, as if only one would be commissioned for a given decision. In that case it would be desirable for an assessment to depend as little as possible on the selection of analysts to perform the assessment. Thus rules of evidence should reduce the degrees of freedom left to analyst judgment, so as to minimize the impact of that judgment on assessment results.

A second desirable feature of an assessment concerns how the results should be qualified. The assessment should communicate an appropriate degree of confidence in its results, and should make clear the limitations of the analysis and current technical knowledge.

Consider now risk assessments as arguments, one on each side of a perhaps many-sided debate. In that case assessments should be as uniform and comparable as possible, so that the debate can focus on comparing aspects of the alternatives themselves, as opposed to unwittingly comparing aspects of the assessments and presentations of the various sides.

Clearly, when the relevant physical processes are poorly understood, widely different sets of assumptions can be defended, so that two different analyses can deliver two different results, both following correctly from the assumptions adopted. While that source of difference cannot be eliminated, the other sources of differences listed in Section III.B. can be minimized by procedural standards for risk assessments, or rules of evidence such as those suggested below.

2. One Suggested Set of Rules of Evidence

a. Clearly define the "risk" being assessed.

As was stressed before, risk is a many-dimensioned concept that is characterized in different ways for different people. Ideally a single, scalar definition of risk would be desirable, and would clarify risk management debates considerably. However, differing characterizations of risk may be such an intrinsic part of the political debate that any consensus on risk definition may not be feasible, or more to the point, such a consensus may be more difficult to .chieve than the resolution of the risk management debate itself. At the very least, then, risk assessments should clearly state what aspects of risk are being assessed, so that differences between assessments due to differing risk measures are recognized as such.

b. Assess risk on measures that capture political concerns.

It hardly helps to measure only expected fatalities when the political process is sensitive to a concern for the potential for catastrophe. One minimal set of risk measures, adopted from Keeney et al, (1979), would be:

(1) Expected fatalities: allows cost/benefit and some value of life calculations to be made.

(2) Individual probabilities of fatality: allows comparison with non-decision "benchmarks" of individual risk, such as smoking, driving a car, etc.,

(3) Individual probabilities of fatality (for members of groups): when grouped by occupation, neighborhood, or activity (recreation, living), allows consideration of equity,

(4) Risk of multiple fatalities: allows incorporation of sensitivity to catastrophe.

c. Be clear on error bounds of results.

Those bounds should include disagreements among experts. This requirement could have the effect of reducing differences among assessments, by forcing all assessments to take into account the same data base: the set of relevant experts or models, as opposed to a single expert or model for each assessment.

d. Be clear on assumptions.

If the assumptions made are clearly stated along with the results, debates over differences between assessments can often be converted into more meaningful debates on assumptions.

e. Be clear on conditional nature of results.

If the assessment is conditional on no terrorist actions, that should be clearly stated along with the results, so that participants in the ensuing risk management debate are clear that they are considering conditional, not absolute, probabilities.

f. Wherever possible, risk measures should be stated in relative terms, relative to an actual, agreed-upon alternative.

Many problems with risk assessment can be mitigated by measuring relative risk, as opposed to absolute risk. One problem with this requirement is that an alternative to the applicant's project should be agreed upon, yet in fact a good deal of the debate may be due to two different ideas of what that alternative should be. If it is possible, though, this requirement would lead to risk assessment results much more easily incorporated into the actual political process, where differences in various dimensions (population risk, environmental quality, etc.) are compared.

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