NORTHWEST ALASKAN PIPELINE COMPANY

FLUOR ENGINEERS AND CONSTRUCTORS, INC.

YUKON RIVER BRIDGE USE RISK ANALYSIS

EXECUTIVE SUMMARY

JANUARY 1982

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FOREWORD

This Executive Summary was prepared by Acres American Incorporated (Acres) in accordance with the terms of contract 4780-9-K208 between Fluor Engineers and Constructors (Fluor) and Acres.

The work summarized in this volume and described in detail in the final study report is a risk analysis of alternative methods for transporting natural gas across the Yukon River in Alaska. Alternative methods include both the use of the existing Yukon Bridge and possible new crossings.

SECTION 1 - THE PROBLEM

1.1 - Introduction

The Yukon River Bridge provides an important strategic link between the North Slope and Alaska south of the Yukon. In addition to carrying vehicular traffic numbering about 100 trucks and cars per day, the bridge also supports the 48-inch pipeline which transports crude oil from the North Slope. Northwest Alaskan Pipeline Company (Northwest) has proposed in its filings with the Federal Energy Regulatory Commission (FERC) to place a second 48-inch pipeline on existing pipeways on the bridge for the purpose of transporting natural gas across the Yukon.

The Yukon River Bridge is a continuous six span structure which was completed in 1976 (see photograph at Figure 1-1). Major superstructure components include a deck, two girders, and two pipeline support bracket assemblies. Five piers of varying heights support the superstructure. The total bridge length is 2,280 feet, with end spans of 320 feet and all interior spans of 410 feet.

While it is technically possible to position the second pipeline as proposed by Northwest, the State of Alaska has requested that a risk analysis be conducted to determine the best method of crossing the river. The existing bridge is regarded as sufficiently critical to the Alaskan and U.S. economies and to the national energy supply system to require careful study of risks and development of a sound basis for the recommended crossing method.

1.2 - The Problem

The problem to be solved is multi-faceted:

(a) There are at least four fundamental crossing methods (or configurations) which might be employed to transport natural gas across the Yukon.

(b) At least 30 different potential risks have been identified and realization of any single large risk magnitude will affect each potential configuration in unique ways.

(c) The consequences of realizing particular risk magnitudes can be measured in terms of six fundamental and important criteria (e.g., oil and gas production losses, oil spills) in addition to total risk dollar value.

FIGURE 1-1

(d) The selected crossing method must not only offer reasonable risk cost expectations, but also it must be compatible with important contingency suitability requirements (e.g., national defense needs).

The problem, then, is to devise a suitable methodology for analyzing potential risks and consequences and to apply the methodology in a consistent way as the basis for selecting a preferred crossing method.

1.3 - Purpose

The purpose of this Executive Summary is to provide a broad overview of the manner in which the problem was attacked and to present important conclusions. Technical details and more rigorous descriptions of procedures and interpretations are provided in the Final Report upon which this summary is based. To a certain degree, this Executive Summary also sets the stage for the interested readers and decision makers whose education and experience may be far afield from the increasingly important risk analysis discipline.

SECTION 2 - THE APPROACH

2.1 - Project Scoping

The first major task undertaken involved a data collection effort and reasonably precise definitions of particular elements to be considered. Figure 2-1 graphically depicts important questions which were addressed at the start and relates them to elements of the analysis. Each element is further subdivided as follows:

(a) Configurations

The primary configurations considered in this analysis are listed below, together with a shorthand notation which appears from time to time elsewhere in the study and on certain figures contained in succeeding sections.

	Configuration	Notation*
1.	The existing bridge with a single oil line	OXX
2.	A gas line placed on the available pipeway on the existing bridge	OXG
3.	A gas line beneath the deck of the existing bridge	OGX
4.	A buried submarine gas line at a separate crossing	OXX-S
5.	A gas line on a separate cable suspension structure	OXX-G

Each of these primary configurations can be further modified to permit additions of one or more contingency (spare) pipelines. Configurations of this latter type were also considered in the analysis, but were treated only with respect to their implications on the above primary configurations.

(b) Risks

Thirty risks were initially identified for consideration in the analysis and were grouped as follows:

* O = Oil pipeline
X = Available location for a pipeline
G = Gas line
-S = Submarine gas line
-G = Aerial gas line

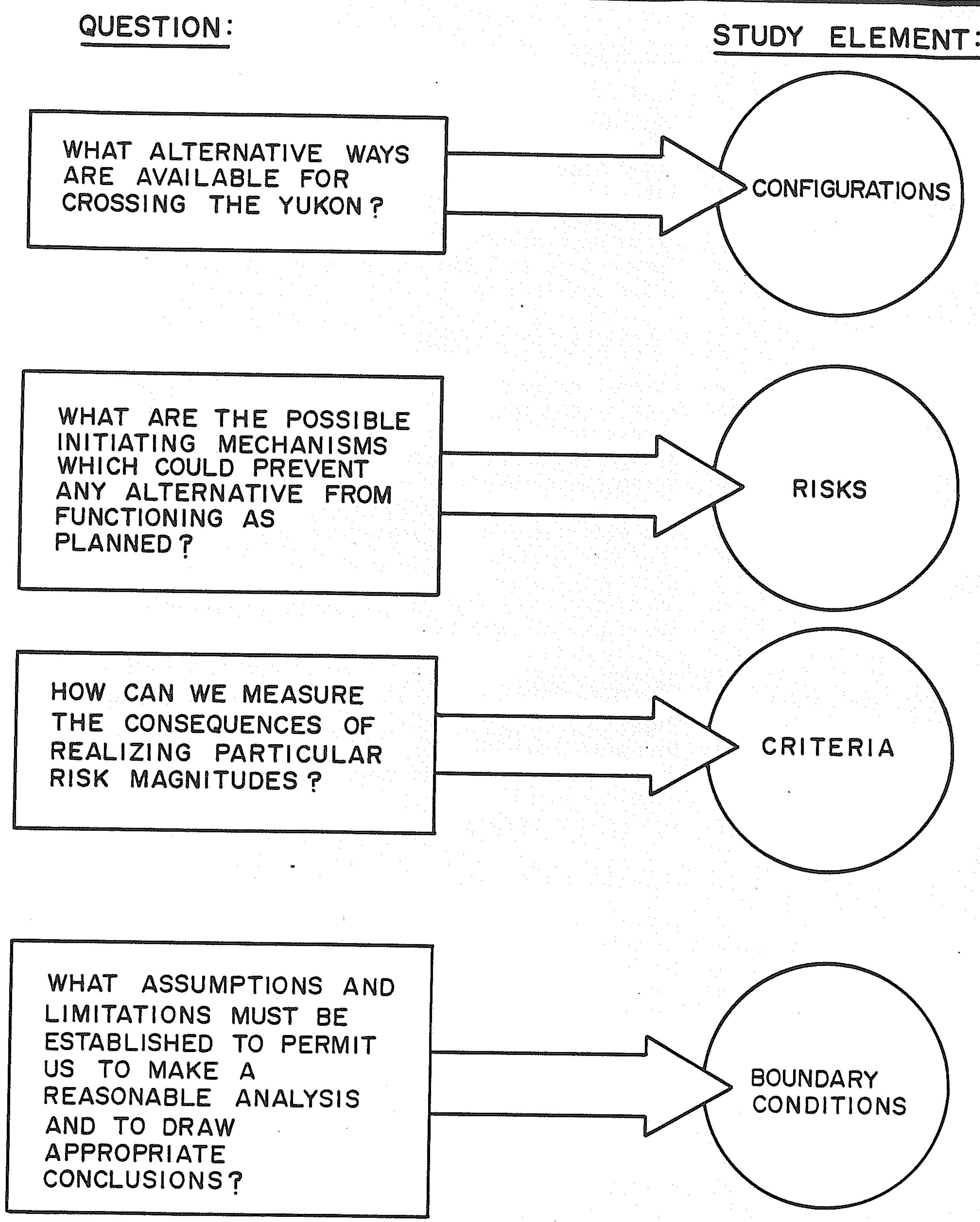

FIGURE 2-1
PROJECT SCOPING QUESTIONS

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(i) Natural Risks

- Wind
- Lightning
- Flood
- River Scour
- Ice
- Earthquake
- Permafrost deterioration
- Temperature extremes
- Slope Instability

(ii) Structural/Mechanical Risks

- Thermal movement
- Excess dead load
- Excess vehicular load
- Bridge metal brittle fracture from a chilled gas leak
- Bridge metal brittle fracture
- Pipeline weld or material flaw
- Gas pipeline crack propagation
- Pipeline leakage
- Pressure surge or overpressure
- Corrosion
- Gas pipeline explosion

(iii) Maintenance Risks

- Pipeline related construction
- Non-pipeline related construction
- Future construction in the bridge vicinity
- Pipeline maintenance activity
- Bridge maintenance activity

(iv) Postulated Events

- Aircraft collision
- Vehicle collision
- Marine collision
- Vandalism
- Sabotage

(c) Criteria

The consequences of realizing particular risk magnitudes were measured in terms of the following criteria:

(i) Oil Production Loss

(ii) Gas Production Loss

(iii) Road Loss

(iv) Oil Spill

(v) Gas Leak

(vi) Repair Cost

(vii) Total Risk Cost

(d) Boundary Conditions

The following assumptions and limitations were established to permit a reasonable and consistent analysis of the problem:

(i) All structures have been or will be competently designed to meet specified design criteria. (Design error was not included as a potential risk.)

(ii) Costs associated with damages and production losses were measured in terms of direct impacts on expected revenues of the transportation company or which are incurred at the crossing site to make repairs, clean up spills, or restore service.

(iii) Where preliminary design of alternative structures has been based upon assumed conditions requiring later detailed field investigations, the basic analysis was conducted as if such assumptions will be verified. A sensitivity analysis was then performed to test the results of potential variations.

(iv) Production losses and road use losses were measured in terms of the time required to restore service. To the extent that regulatory and institutional delays occur, these are additive to values expressed in the study.

(v) Where data gaps were found in assessing probabilities, subjective group judgements were made by appropriate experts in various technical disciplines. These judgements were then tested with a sensitivity analysis.

(vi) The risk analysis was limited to the operation period of each alternative configuration. Risks during the period of construction of the natural gas pipeline will exist and the consequences of realizing any of them may differ from those associated with the operation period. The construction period is short-lived, however, and the assumption has been made for purposes of our study that whichever configuration is ultimately employed, it will be constructed in accordance with the design and that accepted construction practices will be used. It has been further assumed that appropriate restrictions and procedures will be devised and applied during the construction period to minimize danger to the existing bridge and the Alyeska pipeline, as well as to limit the potential for environmental degradation.

2.2 - Methodology

The flow chart at Figure 2-2 illustrates the manner in which individual tasks were performed to arrive at the quantitative values and conclusions appearing in succeeding sections of this Executive Summary. Task 1, Project Scoping, was addressed in paragraph 2.1 above. Succeeding tasks are briefly summarized below:

(a) Task 2, Technical Evaluation

This task brought together the skills of a wide variety of technical experts. Indeed, one of the principal advantages of the formal risk analysis technique is its role as a framework for the integration of information and judgement from a variety of sources.

We began by defining credible events and risks in detail. Whereas flood was identified as a risk in the scoping task, for example, we sought here to define the magnitudes of flood which could conceivably occur and to associate with each magnitude the probability that it will occur. (For the convenience of the reader, probabilities are expressed in the study in a variety of mutually compatible ways. Two of the most important ones are: (1) A decimal value. For example, a probability of .15 for a given risk magnitude is equivalent to suggesting that in a 100 year period, this risk magnitude is expected to be realized 15 times; (2) A return period. For example, a return period of 6 years and 8 months for a particular risk magnitude implies that on the average over a long period of operation, 6 years and 8 months will be the time between occurrences of this risk magnitude. Note that the return period in this example is simply the inverse of the decimal value.)

In each case, we sought to find firstly a maximum credible event (What is the worst possible magnitude, however implausible, that could apply to this risk?) and then to choose selected ranges for lesser, but nonetheless significant, events.

Having defined the risks, we had then to conceptualize the consequences of realizing each selected risk magnitude. (If this risk magnitude is realized, what will happen? Will the crossing fail? Will a spill occur? Must traffic be delayed?, etc.) Recognizing that until or unless a particular risk magnitude is realized, no one can state unequivocally what its consequences will be, we defined a range of damage scenarios and associated with each of them the probability that it will occur.

Even if a particular damage level is suffered, uncertainty remains as to how much it would cost to make repairs, how long it would take to restore service, how much oil would be spilled. We estimated the most likely values for each evaluation criterion (see paragraph 2.1 (c) above) and bounded the most likely value by a minimum (the results of

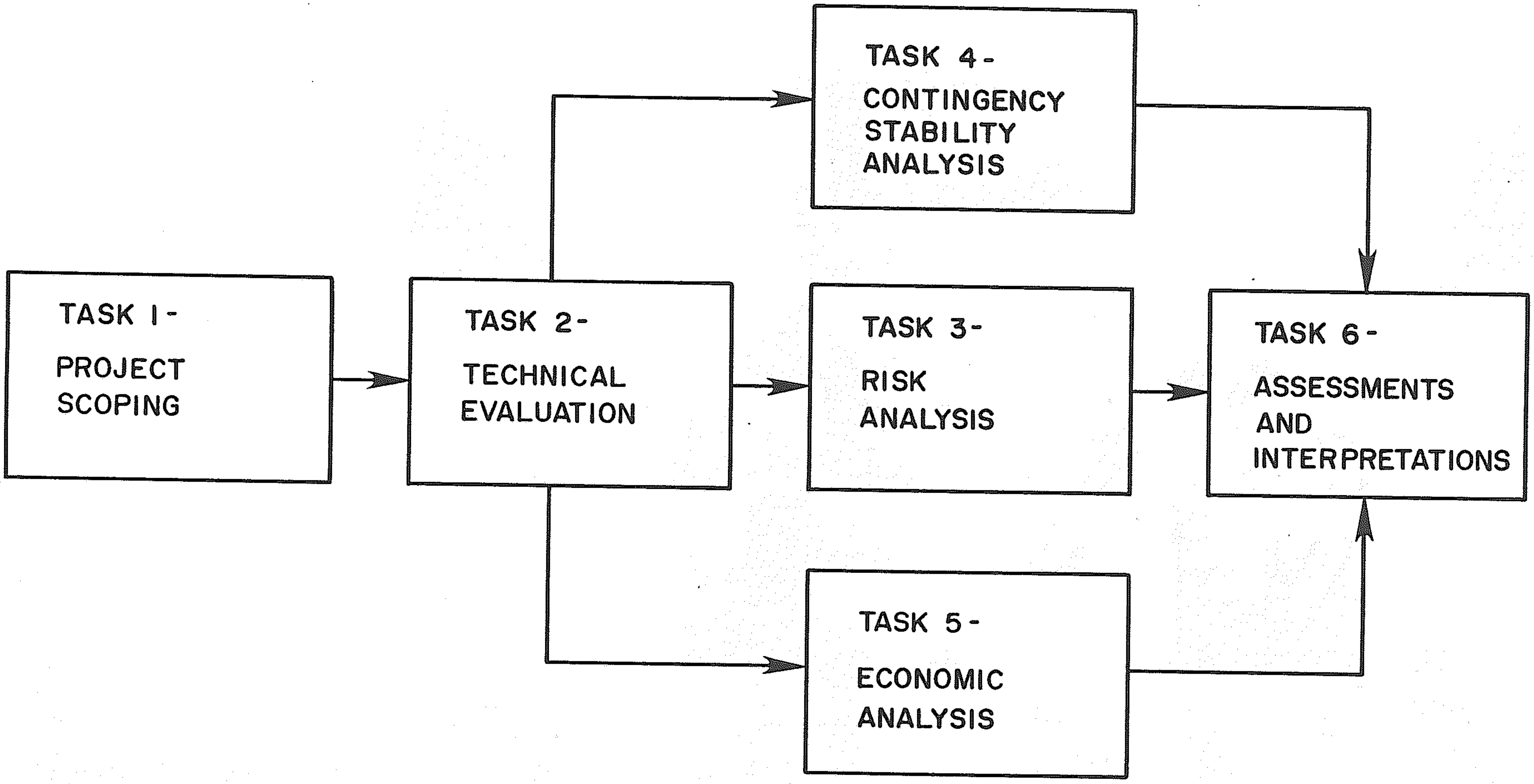

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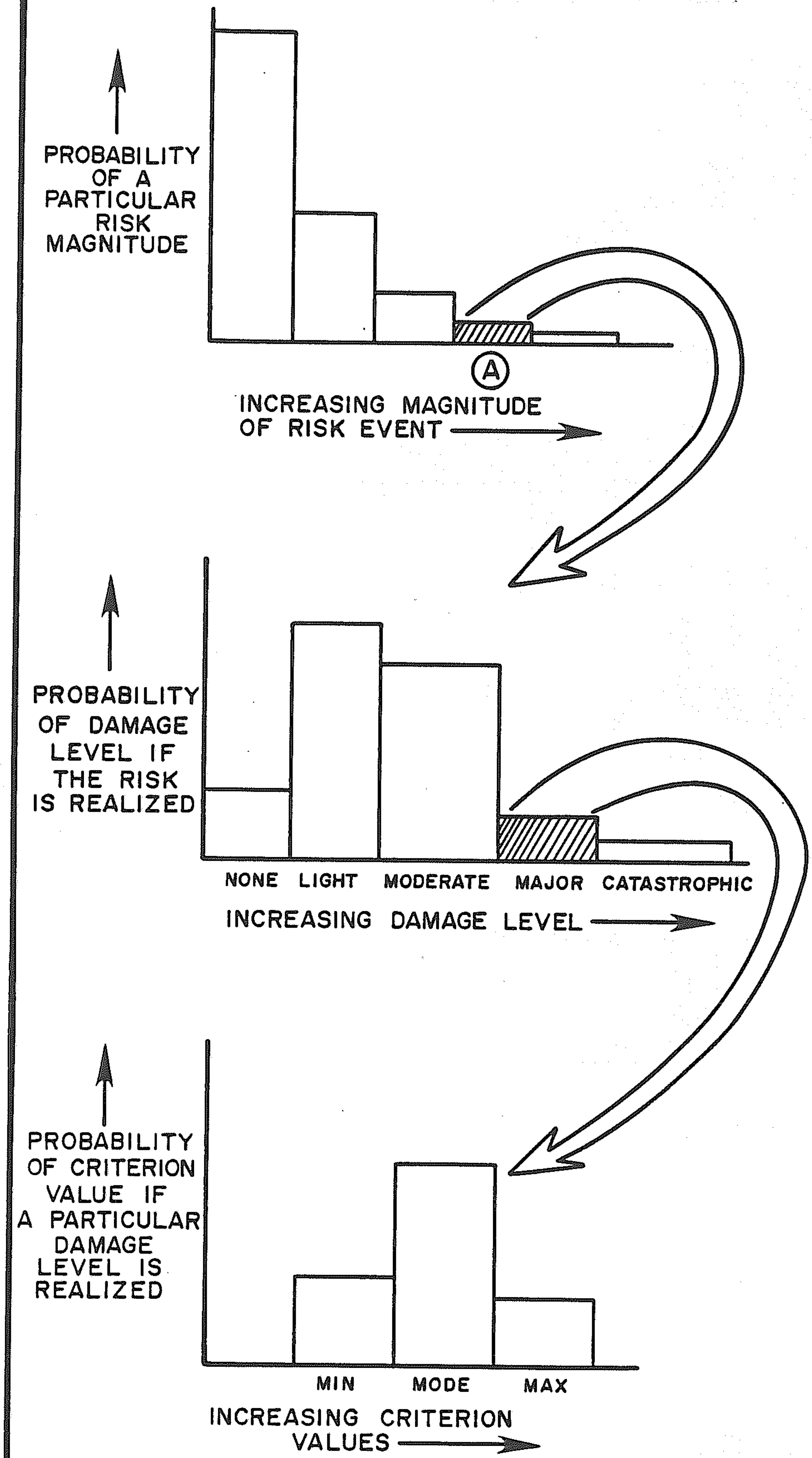
FIGURE 2-2
STUDY METHODOLOGY



(1.) A PROBABILITY LEVEL IS DEFINED FOR EACH RISK EVENT MAGNITUDE.

(2.) IF A RISK EVENT OCCURS, IT CAN CAUSE A NUMBER OF POSSIBLE DAMAGE SCENARIOS, EACH OF WHICH HAS A PARTICULAR PROBABILITY OF OCCURENCE. THUS IF AN EVENT OF MAGNITUDE (A) IN THE RISK DISTRIBUTION OCCURS, THE PROBABILITY IT WILL CAUSE MAJOR DAMAGE APPEARS IN THE SHADED AREA ON THE LEFT.

(3.) A RANGE OF CRITERION VALUES (E.G., OIL OR GAS PRODUCTION LOSS, OIL SPILL, ROAD LOSS, ETC.) IS ASSIGNED FOR EACH DAMAGE LEVEL.

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FIGURE 2-3

STRUCTURAL RELATIONSHIP FOR HANDLING RISKS, DAMAGE SCENARIOS, AND CONSEQUENCES

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everything going smoothly when repairs are made) and a maximum (allowing for the possibility that an abnormally large set of problems will be encountered in restoring service).

Figure 2-3 illustrates the structural relationship for handling risk magnitudes, damage levels, and evaluation criteria.

(b) Task 3, Risk Analysis

Literally hundreds of thousands of individual calculations are involved in assessing the expected risk costs for each of the candidate crossing configurations. A special proprietary computer program was tailored for the Yukon Bridge Risk Analysis. To ensure the validity of the results it produced, we performed manual computations for a portion of the total data set and checked these against the computer output.

(c) Task 4, Contingency Suitability Analysis

Whereas the formal risk analysis conducted in Task 3 provides the basis for assessing selected criterion values, it does not directly address the strategic implications of realizing various risks. We conducted a separate contingency suitability analysis to consider such important issues as the impact of production losses on U.S. energy supply, national defense requirements for the Yukon crossing, and limitations which might be imposed upon the present traffic flow across the river.

(d) Task 5, Economic Analysis

It was essential to establish a consistent set of economic evaluation rules so that competing candidate configurations could be properly compared. This task involved selection of economic parameters, cost estimation for each damage scenario, and the development of transformations which relate each evaluation criterion to an equivalent dollar value. (Note that the transformations were not necessarily simple ratios. In this regard, for example, it was assumed that up to three days of oil or gas production loss could be made up in a single year. Longer outages would for all intents and purposes never be made up because of constraints on field production capacity, pumping capacity, and allowable average throughput.)

This task also included an important environmental assessment of the potential impacts associated with the consequences of realizing risks at each alternative configuration.

(e) Task 6, Assessments and Interpretations

It was in this task that we compared the relative advantages and disadvantages of alternative crossing methods and arrived at conclusions as to the preferred choice. We also conducted a number of sensitivity analyses, particularly for those cases where a fair degree of uncertainty existed with respect to certain risk probabilities or to assumed conditions which have not yet been verified by field investigations.

SECTION 3 - ASSESSING THE RISKS

3.1 - Design Criteria

Any time that a major structure is designed and constructed, it must be capable of withstanding a reasonable range of relatively unusual extremes. Standard procedures and codes must be satisfied and in many cases, proof tests must be conducted before a new facility is allowed to operate. Thus, the Yukon River Bridge was designed not only to withstand average loads which are normally encountered annually, but also to function even when the temperature is abnormally low or the ice cover unusually thick or the river stage especially high. Even so, it is possible that during the useful life of any facility, some condition may be encountered which exceeds the original design criteria. Such events tend to be extremely unlikely. Yet, there is a chance that they can occur. Our analysis focused upon unlikely events.

It is useful to consider the spectrum of possible flood magnitudes at the bridge site as an example. Figure 3-1 illustrates the continuous range of possible flow values for the Yukon in the project area and relates them to certain points of interest. Similar spectra can be drawn for other natural risks (see paragraph 2.1 (b)(i)). It is generally true that the design criteria for the existing bridge and for other alternative configurations is conservative.

A conceptual sketch relating the probability that a particular risk event will be exceeded to increasing size of the event is presented in Figure 3-2. While precise values for probability and for event size will vary from risk to risk, the shape of the curve remains essentially the same for most risks. Figure 3-2 may be interpreted as follows:

Beginning with an event size of zero and moving to the right on the curve, we see that there is a probability of 1.0 (in other words, a certainty) that some event magnitude is always present. (For example, there is always <u>some</u> flow in the Yukon no matter how dry a particular year may be.) The fact that the minimum recorded value for this risk has a high probability of being exceeded in any year is to be expected. The fact that this probability is less than 1.0 suggests that lesser values <u>may</u> be recorded in future. The curve falls off sharply to indicate relatively low probabilities of exceedance for maximum recorded values and for values associated with design criteria. The long tail asociated with events exceeding design criteria represents the particular range of interest with which we are concerned in the risk analysis. Simply stated, we are interested in extremely unlikely occurrences, but their importance lies in the fact that if they are realized, the consequences could be serious.

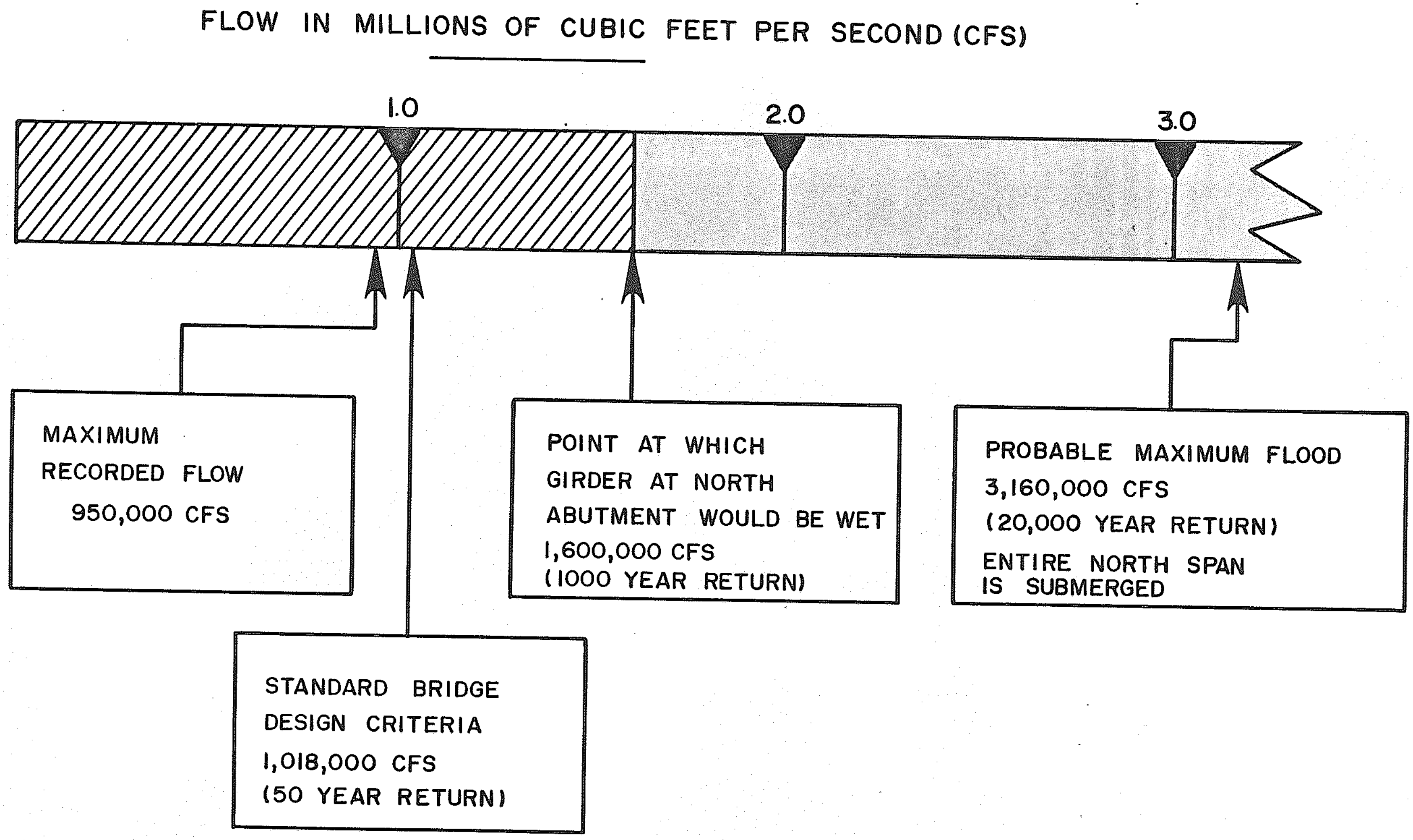

FIGURE 3-1
THE SPECTRUM OF POSSIBLE FLOW VALUES AT THE PROJECT SITE

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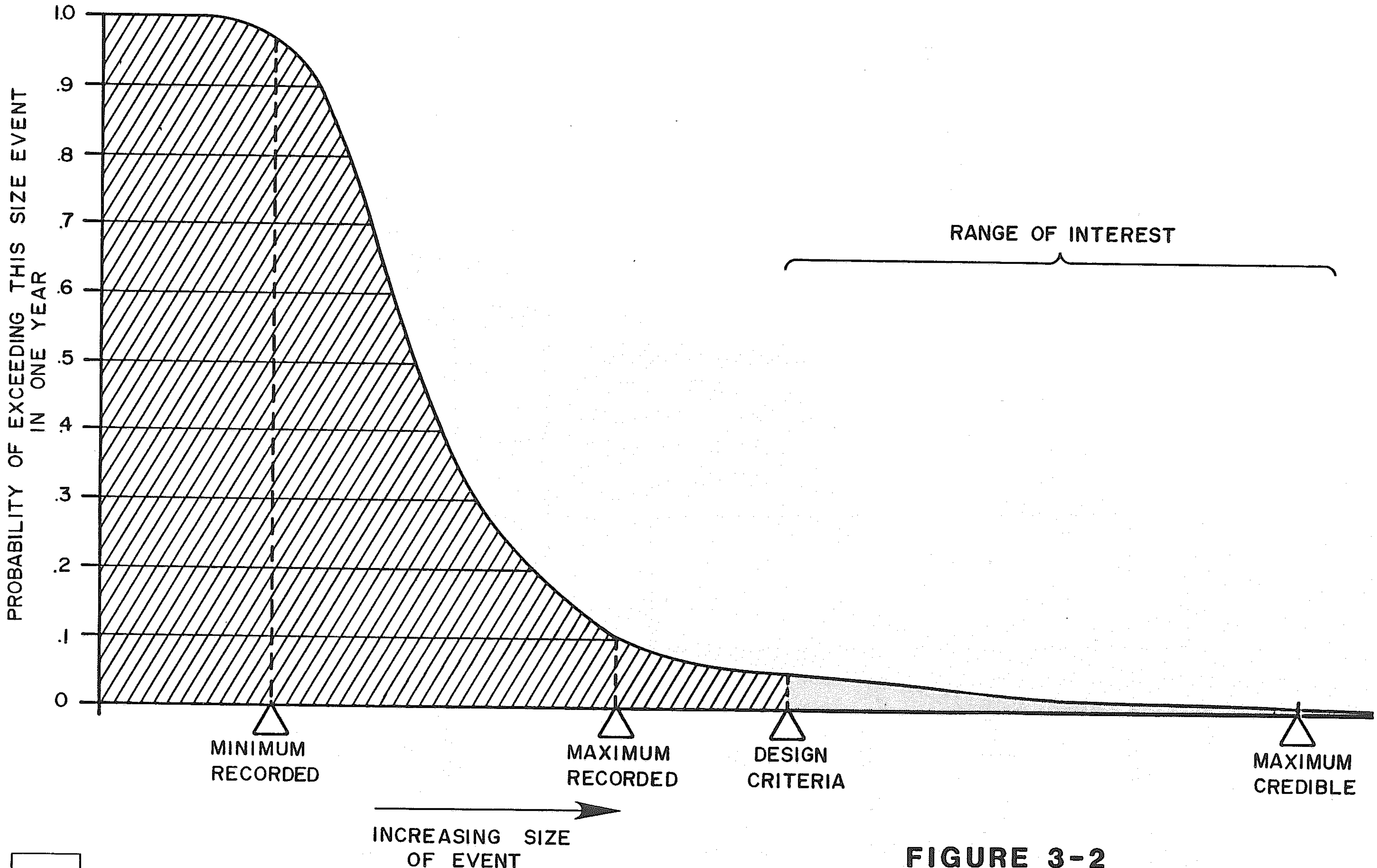

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FIGURE 3-2
CONCEPTUAL RISK MAGNITUDE DISTRIBUTION

3.2 - Determining Risk Probabilities

Each of the risks identified in paragraph 2.1 (b) was analyzed in some detail and the probability that particular risk magnitudes will be exceeded in any given year was determined. It is important to note that the probability of exceeding a certain risk magnitude is in most cases independent of the various configurations. That is to say, for example, that the probability of extreme winds of a particular magnitude does not depend upon what structure they may blow against. The probability that certain damage levels will be suffered does, however, vary from configuration to configuration (see Section 4).

With the exception of the postulated risk category (see paragraph 2.1 (b)(iv)), data was reasonably available to quantify risk probabilities. Subjective judgement and group decision conferences were used to produce values for postulated risks. In this regard, for example, it was judged that the recurrence interval for vandalism will be 10 years. Since it is common knowledge that the Alyeska Pipeline Company has experienced a number of incidents of vandalism, it might seem at first glimpse that the 10 year return period should be shortened. It must be kept in mind, however, that our consideration of vandalism is confined solely to vandalism at the Yukon crossing--perhaps half a mile of a total length of 800 miles or more and at a point where security surveillance is unusually high. Sensitivity analyses were accomplished where uncertainties in the data base existed (see Section 6).

SECTION 4 - ESTIMATING CONSEQUENCES

4.1 - Damage Scenarios

Each alternative configuration is comprised of a number of major components. (In the case of the existing bridge, for example, components include piers, girders, deck, abutments, pipeways, pipelines.) We sought to define a series of damage scenarios which generally described potential failure mechanisms for various components in each configuration. For each such scenario, we estimated the repair costs, oil production losses, spill potential, and other criteria. To the extent possible, this was done independently of risks. (In this regard, for example, a rupture in the oil pipeline would result in an oil spill, production losses, and repair costs regardless of whether the rupture results from sabotage, vehicle collision, or various other risks.)

Having separately determined the probability that specified risk magnitudes would be exceeded and the definition of various damage scenarios, we reviewed each risk magnitude to identify which of the damage scenarios might possibly result from realizing the risk. The structural relationship for handling risks and damage scenarios was earlier discussed in paragraph 2.2 (a).

SECTION 5 - INTERPRETING THE RESULTS

5.1 - Presentation of the Data

A variety of formats is available for presentation of the risk analysis results. Figure 5-1 illustrates three common methods.

The density form ((2) on Figure 5-1) is least satisfactory since the decision maker tends to be less concerned about the probability of incurring a particular criterion value than he is about his chances of limiting his annual exposure to a specified maximum value.

Of the two remaining distributions, the reverse cumulative form ((3) on Figure 5-1) was introduced conceptually when individual risk probabilities were addressed in Section 3. The reverse cumulative is particularly useful when analyzing individual risks and relating them to known values (e.g., design criteria, recorded values).

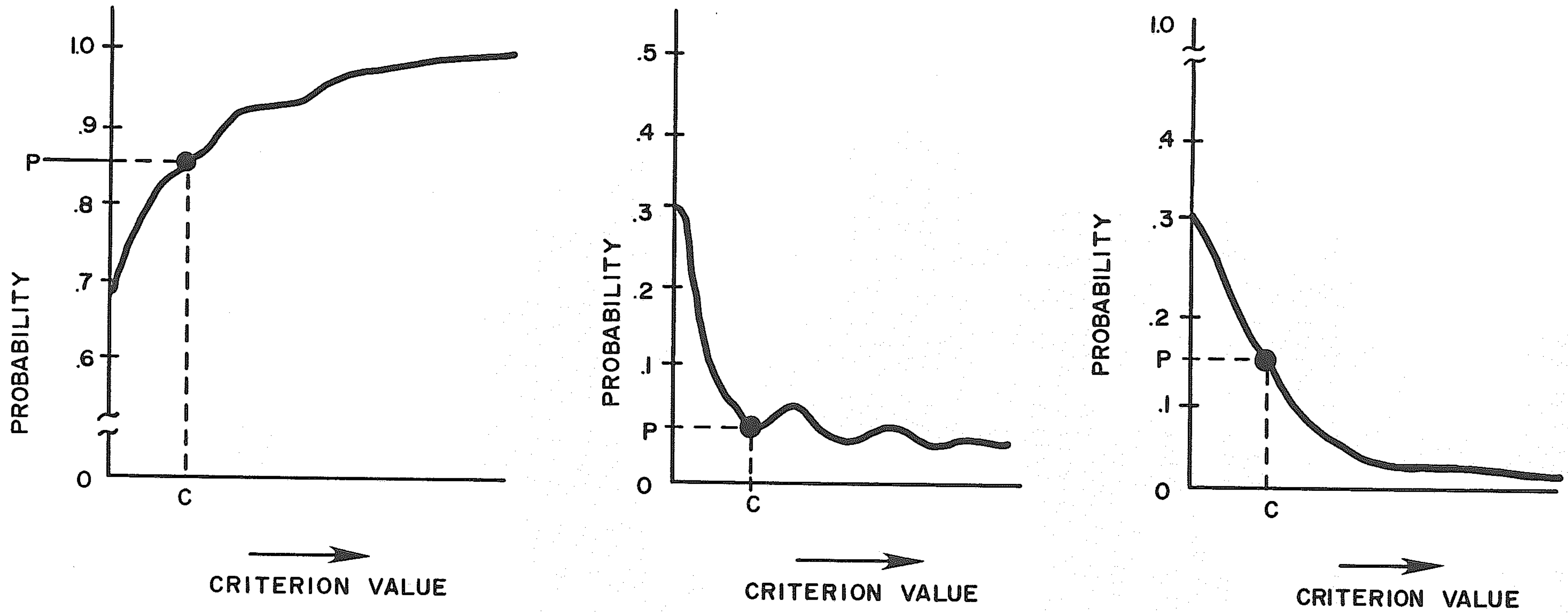
When all risks are considered in aggregate form for one or more configurations, we prefer the cumulative distribution ((1) on Figure 5-1). It provides us with a direct measure of the confidence we can have that specified criterion values will not be exceeded in a given year. Results are consistently presented in the study report as cumulative distributions.

5.2 - The Base Case

Northwest has asserted that the preferred method for crossing the Yukon is to place the natural gas pipeline on the available pipeway on the existing bridge. We have therefore regarded this configuration as the base case. Figure 5-2 provides a plot of the probability that indicated dollar risk costs will not be exceeded. This figure is useful in the sense that it illustrates that there is a very high probability (about .94) that no risk costs will occur in any given year, corresponding to a return period of 17 years for incurring any risk costs at all. The probability that total risk costs will not exceed $5 million in any year is about .99, corresponding to a return period of 100 years.

5.3 - The Existing Structure

While the cumulative distribution for the base case suggests that there is a relatively high degree of confidence that no risk costs will be incurred at all, it is important to determine what the difference in risk terms is between the bridge as it now stands (OXX) and the bridge as it would be if a natural gas pipeline were placed on the pipeway (OXG). Figure 5-3 pro-



(1.) CUMULATIVE DISTRIBUTION

ANY POINT ON THE CURVE INDICATES THE PROBABILITY (P) THAT THE CRITERION VALUE (C) WILL NOT BE EXCEEDED.

(2.) DENSITY FORM

ANY POINT ON THE CURVE INDICATES THE PROBABILITY (P) THAT A PARTICULAR CRITERION VALUE (C) WILL BE INCURRED.

(3.) REVERSE CUMULATIVE

ANY POINT ON THE CURVE INDICATES THE PROBABILITY (P) THAT THE CRITERION VALUE (C) WILL BE EXCEEDED.

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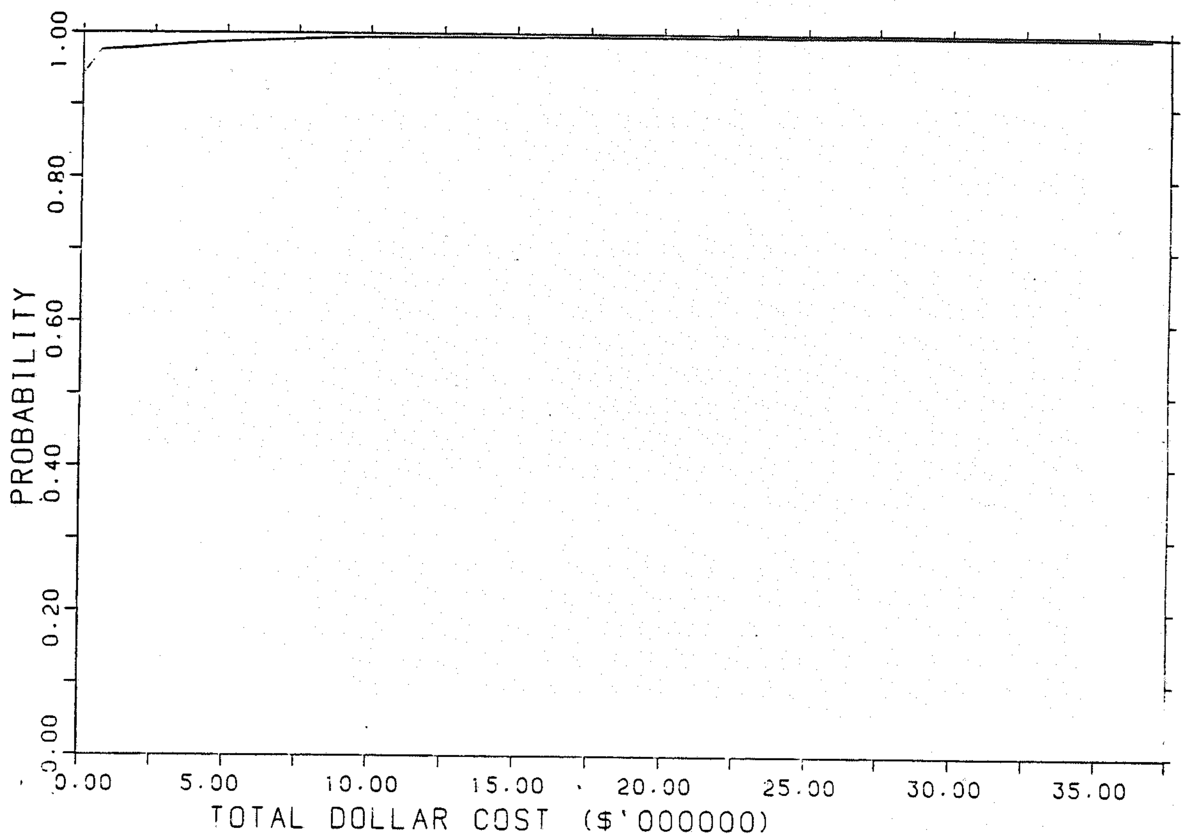
FIGURE 5-1
ALTERNATIVE FORMATS FOR PRESENTING THE ANALYTICAL RESULTS

CONFIGURATION: OXG
CRITERION: TOTAL DOLLAR RISK COST ($'000000)

DISTRIBUTIONS PLOTTED BY SOURCE OF RISK



BASE CASE OXG ALL RISKS 1981$

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FIGURE 5-2

vides such a comparison, excluding only the risk costs associated with gas production loss and gas leaks.

(Note that the vertical scale on Figure 5-3 has been expanded so that we can focus upon important information which had appeared only at the top of Figure 5-2.)

Figure 5-3 may be interpreted to mean that addition of a natural gas pipeline to the existing bridge causes only a marginal change in the risk exposure which now applies there.

5.4 - Other Configurations

Figure 5-4 compares the base case with other configurations in terms of total dollar risk costs. (See Section 2.1 (a) for the meanings of codes OXG, OGX, etc.)

In terms of potential high cost risk exposure (above $5 million), OXG is slightly preferred to OGX and is more clearly preferred to OXX-S and OXX-G. If we focus upon more likely, but less costly, risk exposure (from 0 to $5 million--the portion of the curves closest to the vertical scale in Figure 5-4), the preference order changes. Reconciliation of this shift is best treated by considering expected values (see paragraph 5-5 below). From the owner's standpoint, however, it would appear that minimizing the potential for catastrophic loss will be more important than optimizing for less serious risk exposure.

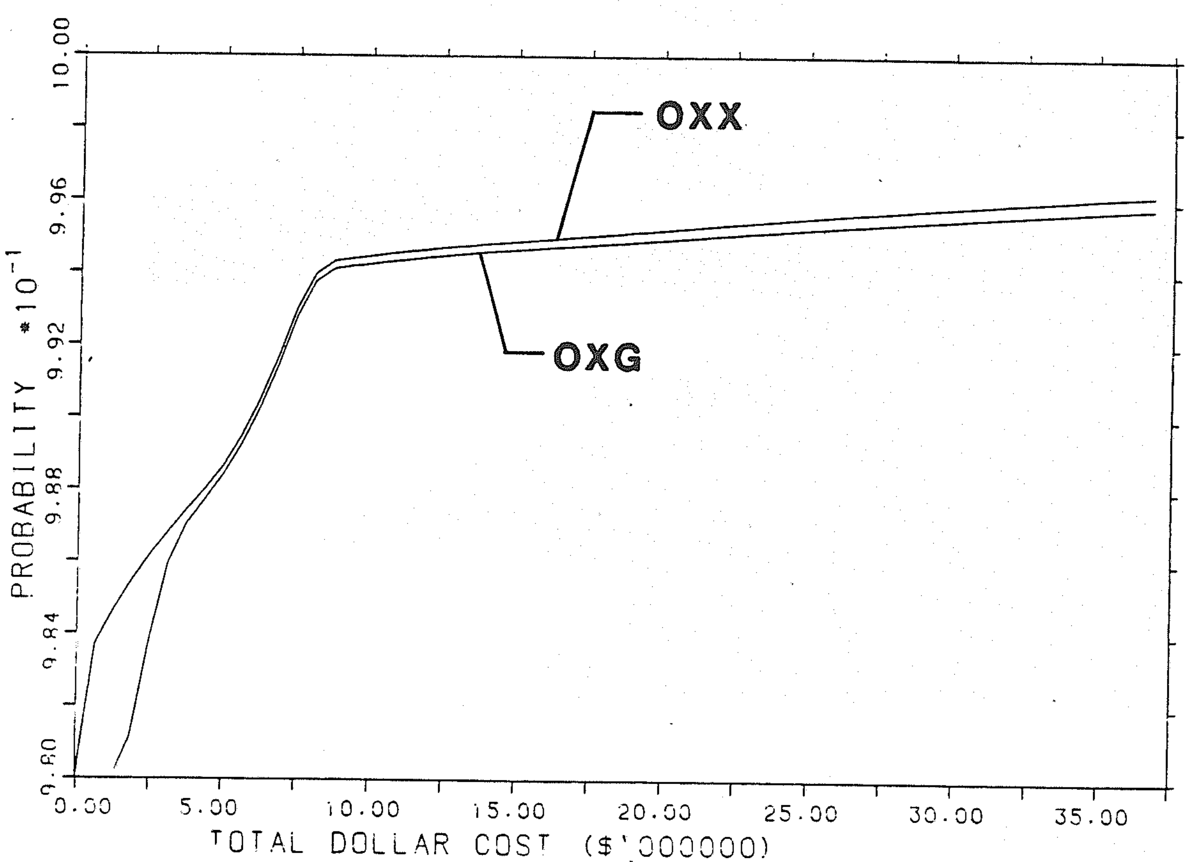
When annual capital, operating, and maintenance costs are added to risk costs, the choice of alternative is more clear (see Figure 5-5). On a total cost basis, the cumulative probability distribution indicates that the base case (OXG) is preferred, followed in order by the below-the-deck option (OGX), the buried submarine crossing (OXX-S), and the cable suspended structure (OXX-G).

5.5 - Expected Values

In addition to considering cumulative distributions relating probability and total cost, it is also useful to view the results in terms of expected values. Expected values are computed by multiplying each possible criterion value by the probability that such a value will be incurred, summing the results. An expected value represents a best estimate of what should happen on the average over a very long period of operation. In this regard, for example, an expected oil production loss of .184 days does not imply that every year this loss will occur, but rather suggests that all losses averaged over a very long period of operation would be equivalent to an average (expected) value of .184 days.

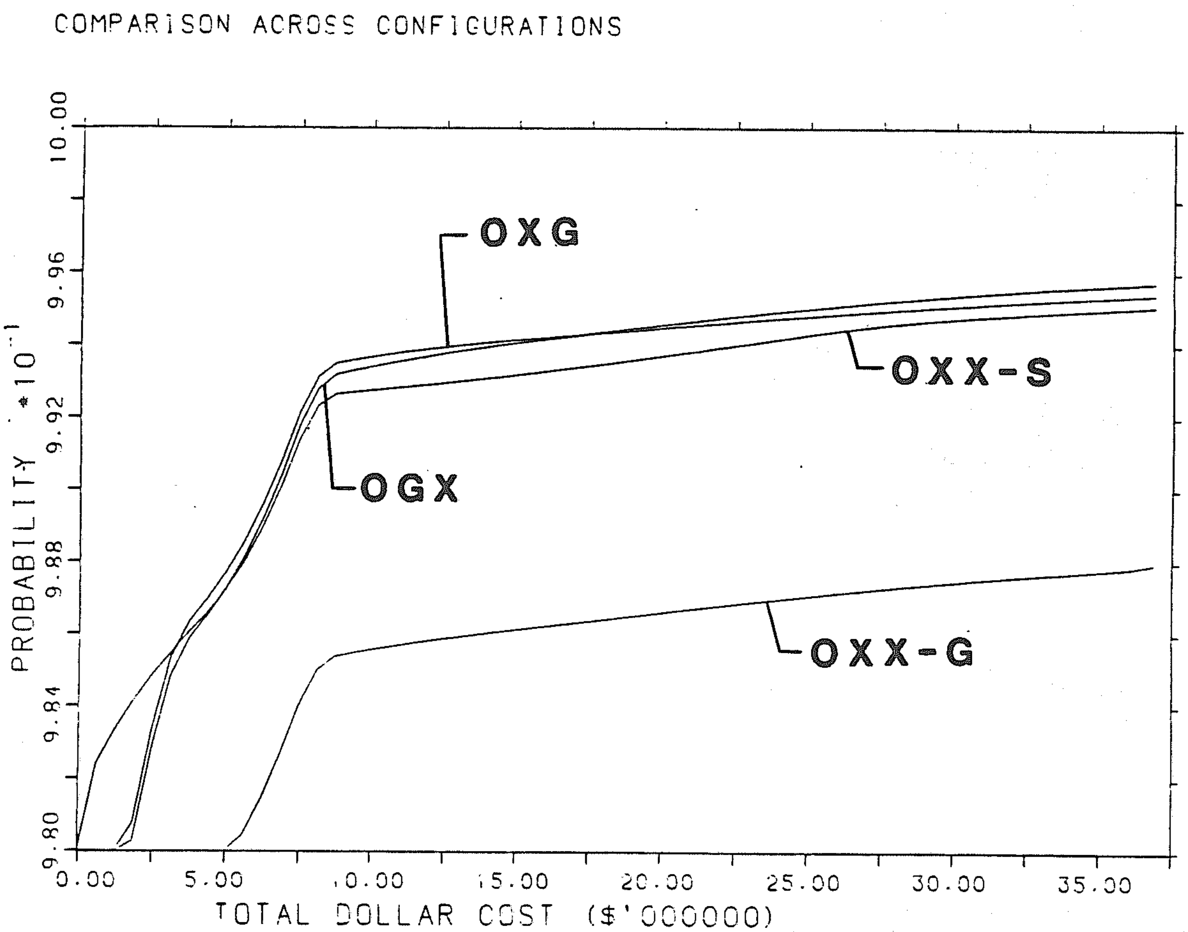
CRITERION:TOTAL DOLLAR RISK COST ($'000000)

COMPARISON ACROSS CONFIGURATIONS



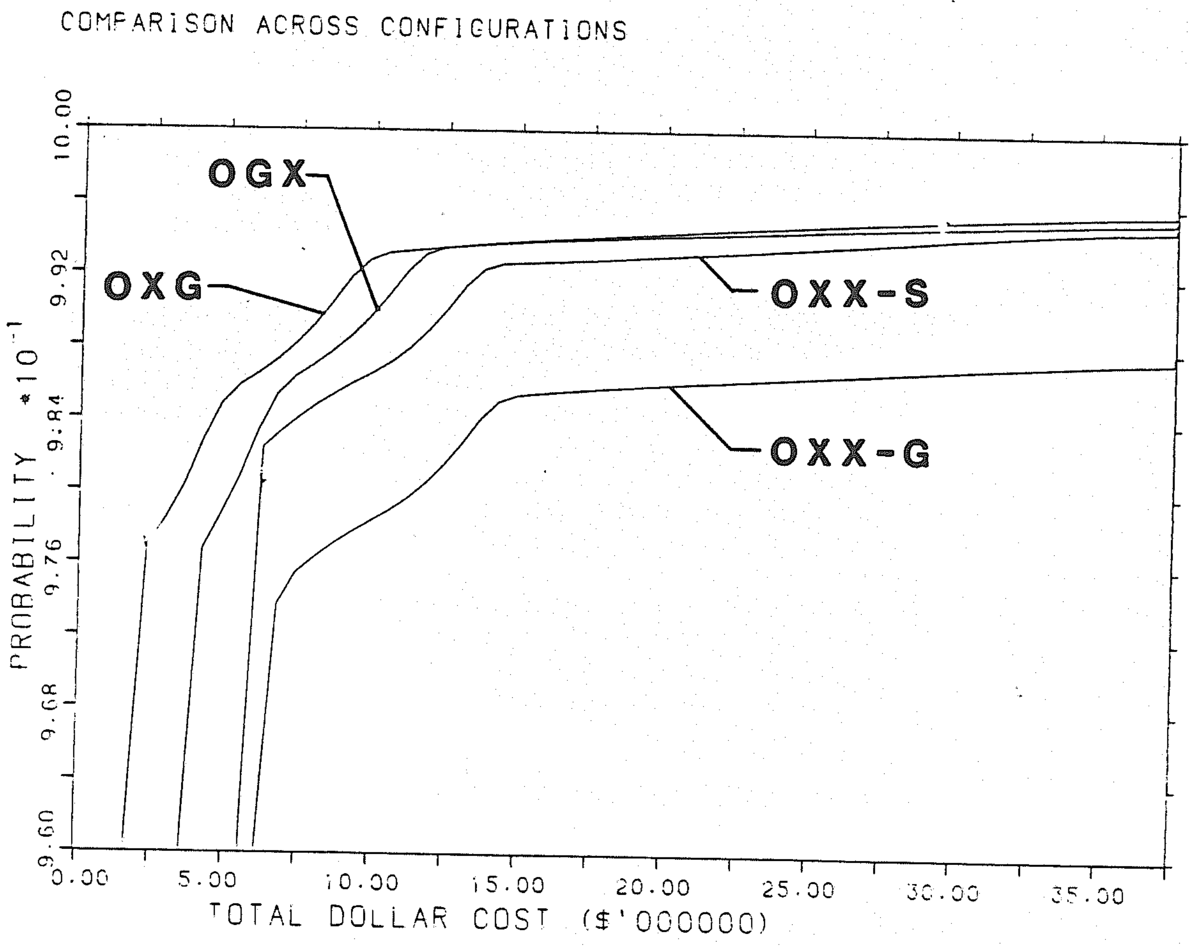
COMPARISON OF OXX AND OXG NON GAS COSTS 1981$

CRITERION:TOTAL DOLLAR RISK COST ($'000000)



COMPARISON OF CONFIGURATIONS 1981$

CRITERION: TOTAL DOLLAR RISK COST PLUS ANNUALIZED CAPITAL, O&M AND SECURITY COSTS (COMS)



COMPARISON OF CONFIGURATIONS 1981$

Table 5-1 provides a summary comparison of expected values of risk costs associated with each of the configurations and with each criterion. This table may be interpreted as follows:

(i) All alternative configurations are essentially equal in terms of expected risk costs for oil production, oil spills, and road loss.

(ii) Natural gas pipeline crossings which do not require use of the existing bridge tend to have lower expected risk costs for gas production loss.

(iii) The submarine crossing (OXX-S) exhibits a lower expected risk cost for gas leaks. This is to be expected since it is not exposed to certain risks such as vehicle and aircraft collisions, wind forces, lightning, and the like. Even so, expected risk costs for gas leaks contribute very little to the total expected risk cost for any configuration.

(iv) Expected repair costs are least for configurations involving use of the existing bridge (OXG and OGX). When separate crossings are involved, expected repair costs are higher since they include both repair costs associated with the existing bridge and those necessary for the added crossings.

(v) If only risk costs are considered and if important assumptions about foundation conditions for the buried submarine crossing can be verified in the field, the submarine crossing is preferred. However, the "benefit" of this apparent reduction in expected annual risk costs (-\$310,000) is outweighed by the increased annual capital, operating and maintenance costs (+\$3,060,000 more than the base case, for a net total annual cost increase of \$2.75 million).

(vi) When total annual expected costs are taken into consideration, the base case (OXG) is clearly favored and the cable suspended crossing (OXX-G) is least favored. The below-the-deck option (OGX) is the second choice and the buried submarine crossing is third (OXX-S).

It is also useful to consider each of the evaluation criterion in terms of its "natural" value. Table 5-2 provides this information. As may be seen from that tabulation, none of the quantities associated with each criterion appears to represent an unacceptably large expected value for the base case.

While expected values provide an indication of the average annual risk quantity which might be incurred over a very long period of operation, it is also important to ask how often a particular consequence will be realized (i.e., what is the return period?) and if it is realized,

TABLE 5-1

SUMMARY OF EXPECTED VALUES OF ANNUAL RISK COSTS
(Millions of 1981 Dollars)

Criterion	OXG	OGX	OXX-S	OXX-G
Oil Production Loss	$1.596	$1.597	$1.591	$1.594
Gas Production Loss	.714	.707	.404	.441
Road Loss	.164	.156	.154	.153
Oil Spill	.032	.032	.032	.032
Gas Leak	.015	.016	.001	.015
Repair	.065	.070	.094	.389
Total Annual Risk Cost	$2.586	$2.578	$2.276	$2.624
Expected Risk Cost Relative to Base Case	0	- .008	- .310	+ .038
Annual Capital, Operating and Maintenance Costs	1.38	2.89	4.44	4.95
Total Annual Costs	$3.97	$5.47	$6.72	$7.57
Expected Total Annual Costs Relative to Base Case	0	+1.50	+2.75	+3.60

TABLE 5-2

"NATURAL" MEASURES OF ANNUAL EXPECTED VALUES

Criterion	OXG	OGX	OXX-S	OXX-G
Days of Oil Production Loss	.184	.184	.182	.182
Days of Gas Production Loss	.181	.177	.098	.111
Days of Road Loss	.432	.411	.405	.402
Barrels of Oil Spilled	180	180	180	180
MMCF of Gas Leak	5.94	6.27	.514	5.69
Repair Costs (1981 $)	$65,000	$69,700	$94,200	$389,000

what magnitude it is expected to have. Table 5-3 provides this information for all criteria and for all configurations.

5.6 - Sensitivity Analysis

Subjective judgements had to be applied at numerous points in the analysis. Some of these judgements were made with reasonable confidence and provisions were made within the calculation routine to reasonably treat uncertainties. For example, we cannot know for sure that a major earthquake will cause a bridge span to collapse. There is at least a small chance that even the maximum credible earthquake would result in less severe damage. This sort of uncertainty was handled by estimating the probability that each of several possible damage scenarios would result from realizing any of the possible risk magnitudes. It was further accounted for by using minimum, modal, and maximum entries when estimating criteria values associated with each damage scenario.

There are other uncertainties, however, which cannot be adequately treated within the risk analysis framework. It is this latter category which we treated in terms of sensitivity analyses. In a sense, a sensitivity analysis allows us to determine how important these uncertainties are in the final selection of a preferred crossing method. Table 5-4 summarizes the results of our sensitivity analysis and presents brief interpretations.

Of the various entries in Table 5-4, we regard item 4 as the most significant.

A great deal of information is of course available to us regarding the existing bridge (alternatives OXG and OGX). Design calculations have been made and a fair amount of data has been collected for the cable suspended alternative (OXX-G). Very little is known, however, about the buried submarine crossing (OXX-S). Extremely important assumptions were made as the basis for defining subsurface conditions beneath the river bottom. Field investigations will have to be conducted if serious consideration is ever given to selection of the buried submarine crossing.

TABLE 5-3

RETURN PERIODS AND EXPECTED MAGNITUDES IF A LOSS OCCURS

Criterion	OXG		OGX		OXX-S		OXX-G	
	Return Period	Magnitude If a Loss Occurs	Return Period	Magnitude If a Loss Occurs	Return Period	Magnitude If a Loss Occurs	Return Period	Magnitude If a Loss Occurs
Oil Production Loss	91.5	.561 mos	91.5	.561 mos	91.5	.561 mos	91.5	.561 mos
Gas Production Loss	104	.627 mos	114	.671 mos	340	1.12 mos	219	.808 mos
Road Loss	108	1.56 mos	107	1.47 mos	104	1.40 mos	102	1.37 mos
Oil Spill	49	8780 bbls	49	8780 bbls	49	8780 bbls	49	8780 bbls
Gas Leak	41	246 MMCF	40	251 MMCF	34	176 MMCF	34	196 MMCF
Repair Costs	22	$1,430,000	25	$1,710,000	25	$2,360,000	22	$8,440,000

PROPRIETARY

TABLE 5-4

SENSITIVITY ANALYSIS

Sensitivity Test	OXG	OGX	OXX-S	OXX-G	Interpretation
1. Base results repeated from Table 2-1 for comparison purposes:					
Expected Total Risk Costs	2.59	2.58	2.28	2.62	1. The base case (OXG) is clearly favored in the original risk analysis runs. The submarine crossing would be the third choice if important assumptions regarding foundations are proven correct in the field.
Annual Costs	1.38	2.89	4.44	4.35	
Expected Total Cost	3.97	5.47	6.72	7.57	
Preferred Ordering	1	2	3	4	
2. Postulated risks are increased by an order of magnitude:					2. A major increase in postulated risk probabilities makes no change in preferred ordering. The base case remains favored, with the below-the-deck option a clear second choice.
Expected Total Risk Costs	8.33	8.05	7.94	9.61	
Annual Costs	1.38	2.89	4.44	4.95	
Expected Total Cost	9.71	10.94	12.38	14.56	
Preferred Ordering	1	2	3	4	
3. Postulated risks are increased by an order of magnitude and the probability of sabotage increases to 1/25 for all configurations:					3. If Yukon crossings are selected as targets by a determined group of dissidents, the base case remains favored, followed by the below-the-deck option (OGX). The submarine crossing becomes least favored.
Expected Total Risk Cost	21.78	20.77	29.23	23.22	
Annual Costs	1.38	2.89	4.44	4.95	
Expected Total Cost	23.16	23.66	33.67	28.17	
Preferred Ordering	1	2	4	3	

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TABLE 5-4 (Cont'd)

SENSITIVITY ANALYSIS

Sensitivity Test	OXG	OGX	OXX-S	OXX-G	Interpretation
4. Foundation conditions are worse than assumed and corrosion risks are increased for the submarine crossing. Thus, earthquake and corrosion risk probabilities increase and capital investment is set at a higher level (increased by 20% over Northwest's estimate):					4. If foundation conditions are worse than assumed for the submarine crossing, the base case (OXG) remains the preferred choice, but the submarine crossing (OXX-S) drops to fourth place behind the below-the-deck option (OGX) and the cable suspended pipeline (OXX-G).
Expected Total Risk Costs	2.59	2.58	2.74	2.62	
Annual Costs	1.38	2.89	5.11	4.95	
Expected Total Cost	3.97	5.47	7.85	7.57	
Preferred Ordering	1	2	4	3	
5. Annualized capital costs are calculated on the basis of a 3% discount rate instead of the 6% rate used in the original analysis:					5. Use of a lower discount rate for calculating annual costs does not change the preferred ordering from that in the original analysis.
Expected Total Risk Cost	2.59	2.58	2.28	2.62	
Annual Costs	1.28	2.39	3.55	3.98	
Expected Total Cost	3.87	4.97	5.83	6.60	
Preferred Ordering	1	2	3	4	

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SECTION 6 - CONTINGENCY SUITABILITY AND ENVIRONMENTAL ASSESSMENT

6.1 - Contingency Suitability

The purpose of the contingency suitability analysis was to consider impacts, limitations, and implications relative to national energy, haul road access, and defense considerations. In general, this analysis found very little distinction among alternatives in strategic terms. Major findings in terms of contingency suitability included:

(a) The potential for significant impact on U.S. energy needs is small for every configuration. Short production losses can be tolerated as a result of elasticity within the overall energy supply system. Indeed, the chance that any failure of a Yukon crossing will cause a gas production loss or an oil production loss in excess of six months in duration is less than one in a million.

(b) An analysis of the extent to which the existing bridge can sustain the loss of one girder without collapsing was conducted by Northwest's design team. Addition of a gas pipeline either on the available pipeway or under the deck will not remove the one girder contingency capability of the existing bridge.

(c) Provided certain modifications are made to increase stiffening of the bridge for the below-the-deck alternative (OGX), all alternatives are essentially equal in terms of limitations on future overload highway transportation across the Yukon.

(d) All alternative configurations can accommodate defense access needs.

(e) Contingency (spare) pipelines are not justified on a total annual cost basis, but at least one available (unused) pipeline location can be found in every alternative considered.

6.2 - Environmental Assessment

An environmental assessment was conducted to consider the impacts of realizing comparable risks at alternative crossings. From the environmental standpoint, an oil spill is the most important risk. As indicated on Table 5-2, however, the expected values for oil spill are the same for all configurations.

While construction risks were not analyzed in this study (see boundary condition (vi) in paragraph 2.1 (d)), it was noted that the most significant potential for disturbance associated with newly routed pipelines occurs with construction of the buried submarine crossing (OXX-S), where blasting and excavation in the river bed would cause significant short-term local effects.

SECTION 7 - CONCLUSIONS

Major conclusions developed in the study include:

(a) Design criteria for the existing Yukon Bridge were in accordance with applicable standards and the bridge is expected to function safely throughout its intended life.

(b) Risk exposure for the existing bridge stems primarily from low probability natural extremes, human and material failures. Even so, the probability that no significant risk costs will be incurred for the existing bridge (with only the oil pipeline on it) in any one year is greater than 97 percent and the return period for risks involving any oil production loss is more than 90 years.

(c) Adding a gas line to the bridge on the available downstream pipeway causes only a marginal increase in expected annual risk costs for all non-gas-specific criteria.

(d) In terms of total annual expected costs during the operating period, the base case solution of placing the gas pipeline on the available downstream pipeway is the preferred choice. This conclusion is insensitive to reasonable ranges of uncertainties in certain subjectively determined data and of projected economic parameters.

(e) In the event that circumstances not related to this risk analysis preclude placement of the gas pipeline on the available downstream pipeway, the next preferred alternative involves placement beneath the bridge deck. The third choice (between the buried submarine and suspended crossings) must necessarily depend upon the relative weighting applied by interested parties to various risk criteria, sensitivity to uncertainties, and other considerations beyond the scope of this analysis. Our own preference for third choice marginally favors the cable suspended structure primarily because of the sensitivity of assumptions to subsurface conditions in the river bed and the environmental implications of installing the submerged crossing.

(f) There is essentially no difference amongst the alternatives in terms of the risks of the environmental impacts due to oil spills, nor does addition of the gas pipeline to the existing bridge make any significant change in current oil spill risks.

(g) The buried submarine crossing is least favored environmentally because of the necessity for dredging, blasting, and filling in the Yukon River.

(h) A contingency oil line or gas line is not justified from a risk cost perspective.

(i) Any future need for a second oil pipeline can be accommodated by each of the alternatives.