U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: ESF ALTERNATIVES STUDY - METHODOLOGY DEVELOPMENT AND PILOT STUDY

PRESENTER: DR. LEE MERKHOFER

PRESENTER'S TITLE AND ORGANIZATION: PRINCIPAL,
APPLIED DECISION ANALYSIS, INC.

PRESENTER'S TELEPHONE NUMBER: (415) 854-7101

JULY 24-25, 1990

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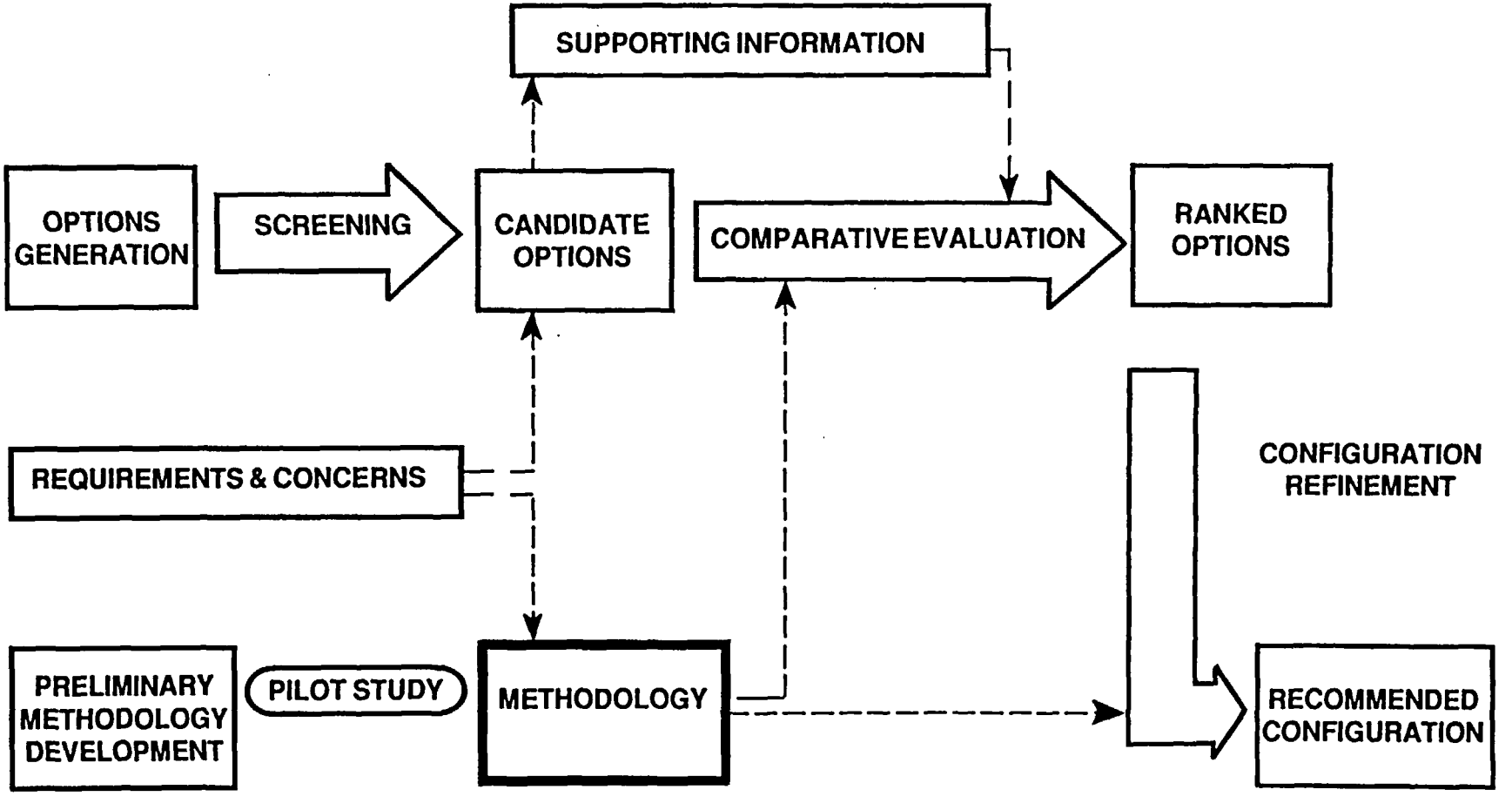
ESF ALTERNATIVES STUDY
DECISION METHODOLOGY



THE OVERVIEW WILL ADDRESS THREE TOPICS

1. DISTINCTIVE CHARACTERISTICS OF THE METHODOLOGY

2. KEY CONCEPTS INVOLVED

3. STEPS TO DEVELOP AND APPLY THE METHODOLOGY

THE METHODOLOGY HAS DISTINCTIVE CHARACTERISTICS DELIBERATELY SELECTED TO MEET SPECIAL NEEDS OF THE STUDY

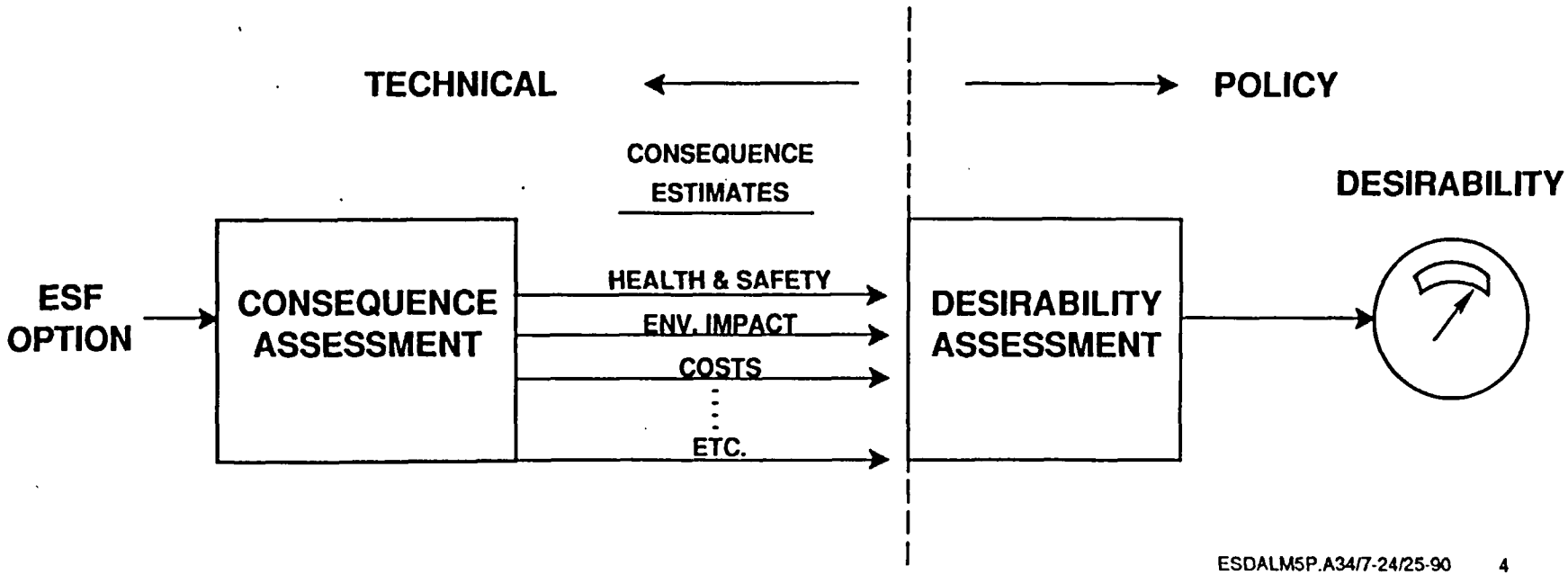
- EXPLICIT CONSIDERATION OF IMPACT OF ESF CHOICE ON DOWN-STREAM DECISIONS (e.g., REGULATORY APPROVAL)
- RELIANCE ON TECHNICAL PANELS TO PROVIDE INPUTS BASED ON INFORMED PROFESSIONAL JUDGEMENT
- EXTENSIVE DOCUMENTATION OF PROCESS
- USE OF FORMAL DECISION ANALYSIS LOGIC (e.g., MULTIATTRIBUTE UTILITY ANALYSIS)

THE METHODOLOGY INVOLVES FOUR KEY CONCEPTS

1. THE LOGIC FOR CONDUCTING THE EVALUATION:

OPTIONS ARE EVALUATED BY ESTIMATING

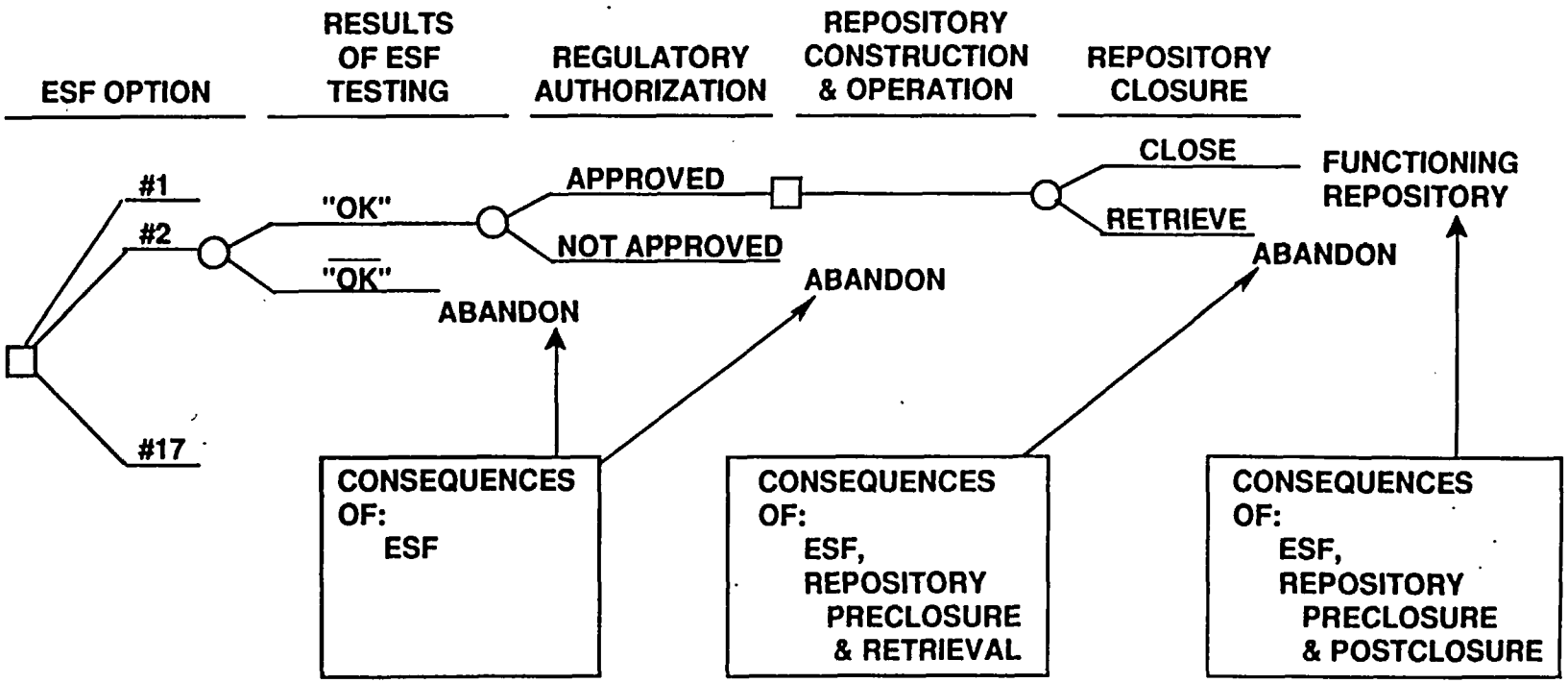
- THE POSSIBLE END CONSEQUENCES OF CHOOSING EACH OPTION
- THE DESIRABILITY OF THE POSSIBLE END CONSEQUENCES AND THEIR LIKELIHOOD



KEY CONCEPTS

(CONTINUED)

2. THE USE OF A DECISION TREE TO SHOW HOW END CONSEQUENCES DEPEND ON SUBSEQUENT DECISIONS AND EVENTS (WHOSE OUTCOMES MAY BE INFLUENCED BY THE ESF CHOICE)



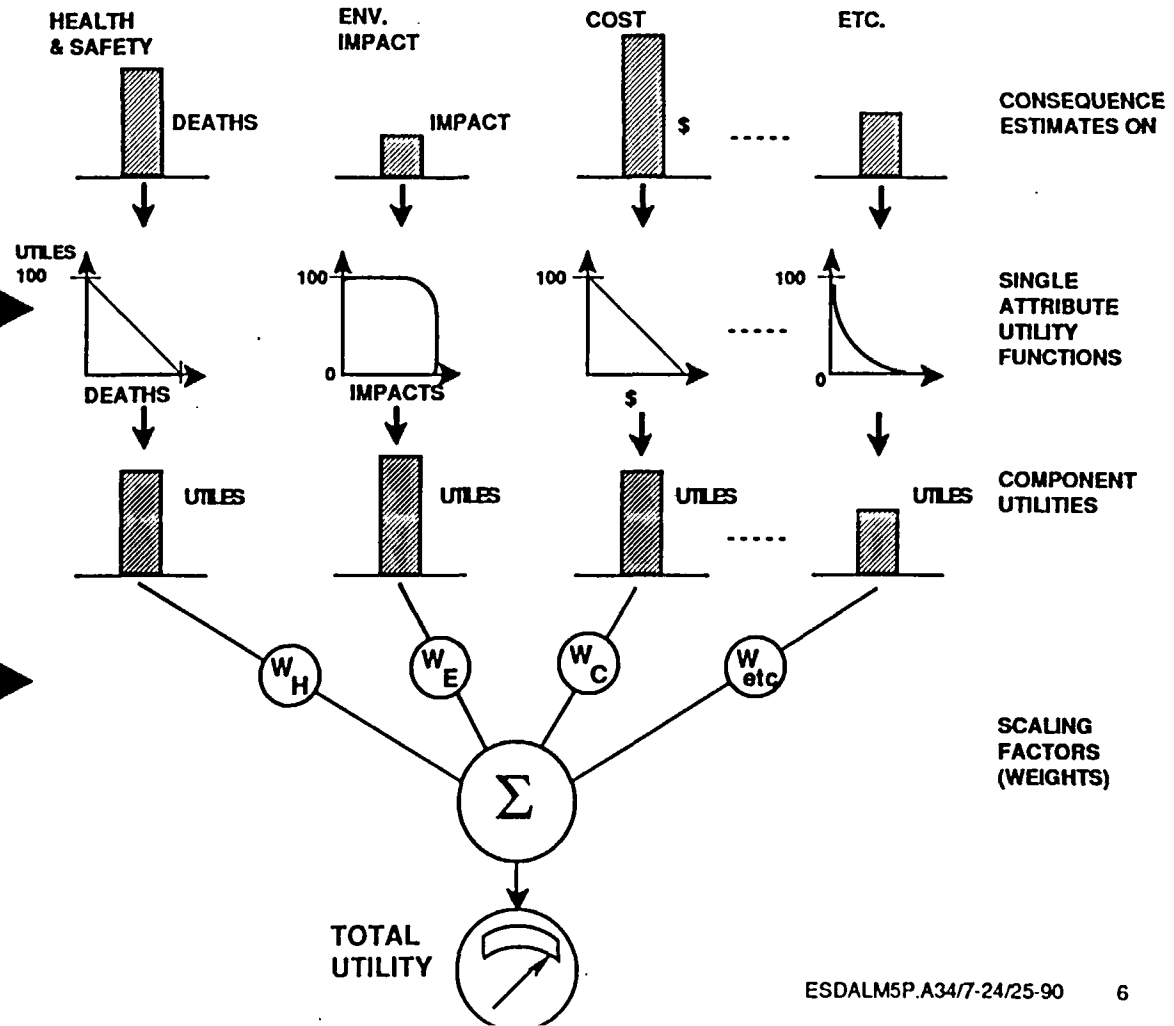
KEY CONCEPTS

(CONTINUED)

3. THE USE OF A MULTIATTRIBUTE UTILITY ANALYSIS (MUA) TO TRANSLATE VARIOUS CONSEQUENCE ESTIMATES INTO A COMMON MEASURE (UTILES) WHILE ACCOUNTING FOR :

- THE RELATIVE DESIRABILITY OF DOING WELL vs POORLY ON A PERFORMANCE MEASURE

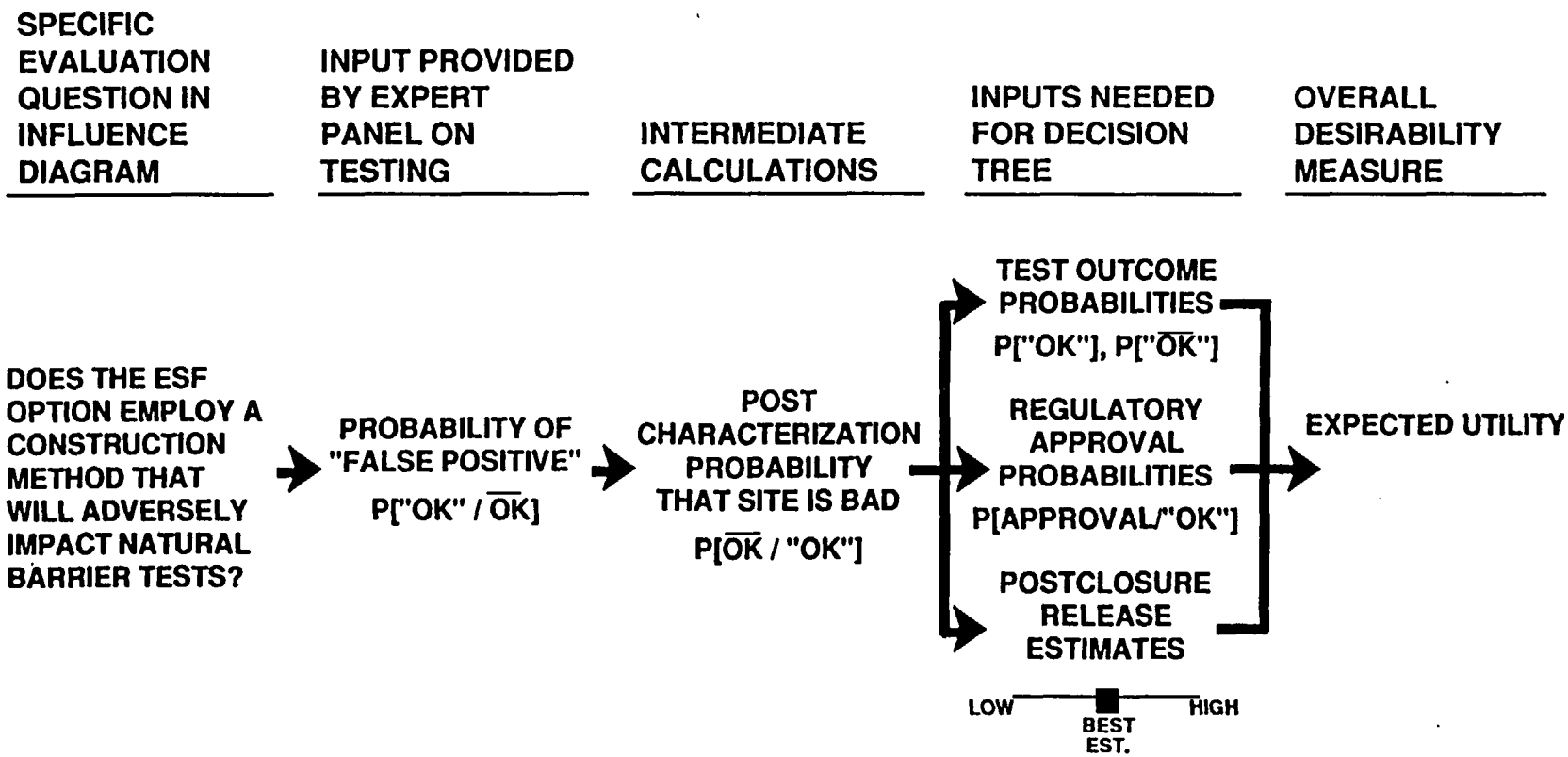
- THE RELATIVE IMPORTANCE OF EACH PERFORMANCE MEASURE



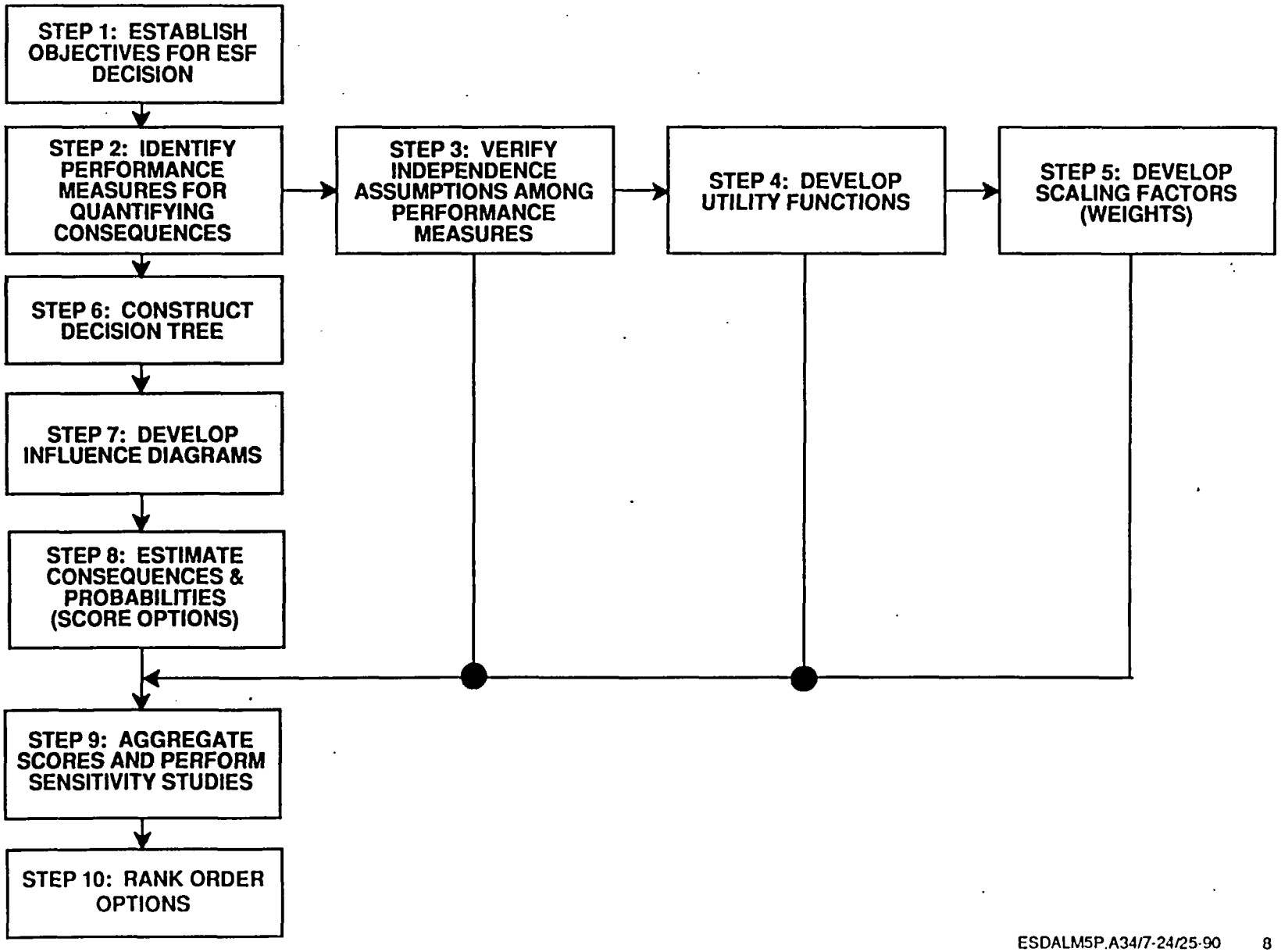
KEY CONCEPTS

(CONTINUED)

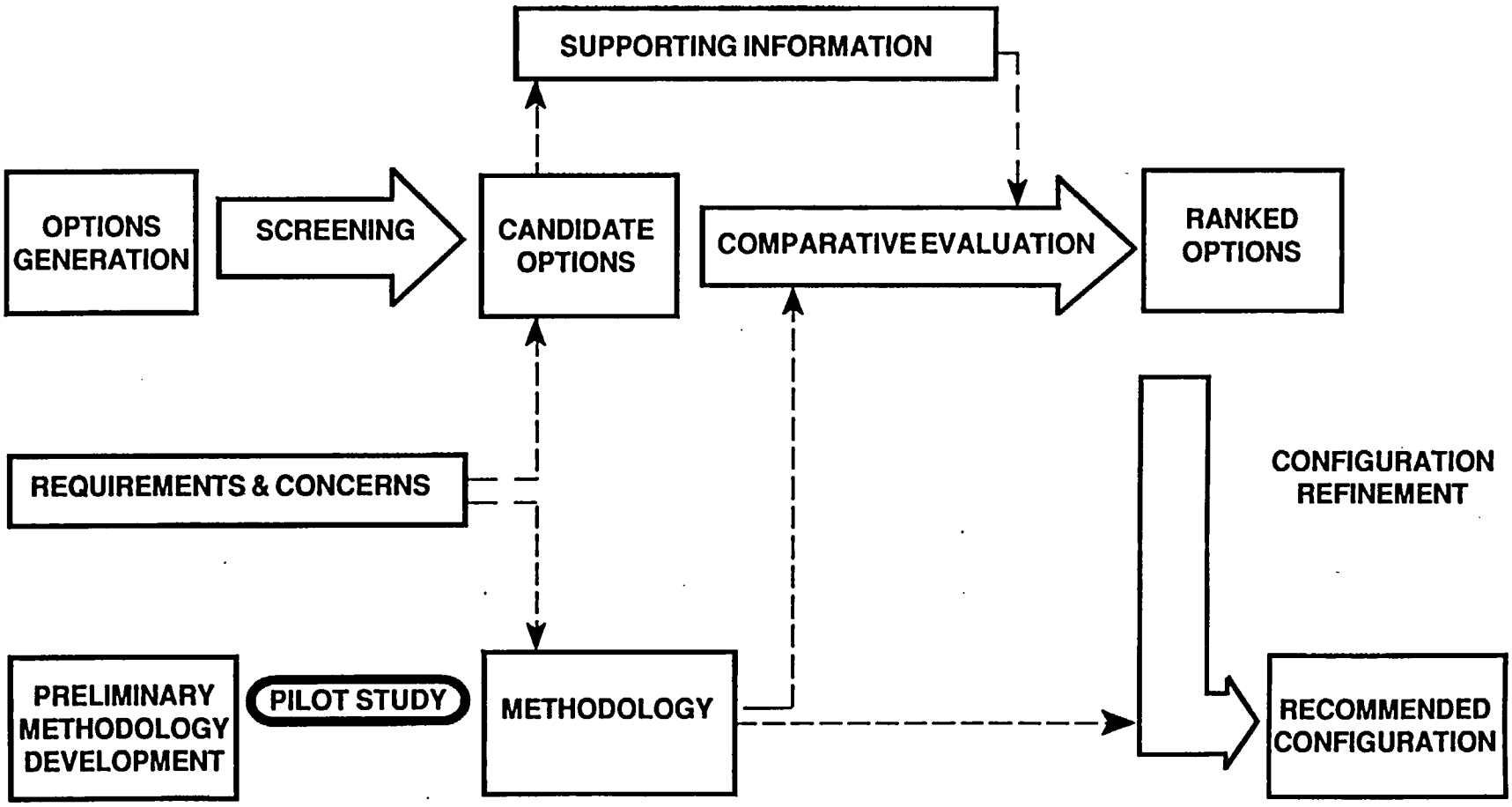
4. THE USE OF INFLUENCE DIAGRAMS AND OTHER ANALYTICAL TOOLS TO RELATE PROBABILITIES AND CONSEQUENCE ESTIMATES TO SPECIFIC EVALUATION QUESTIONS



STEPS TO DEVELOP AND APPLY METHODOLOGY



ESF ALTERNATIVES STUDY
PILOT STUDY



ESOVTH5P.A33/7-24/25-90

THE PILOT STUDY PRESENTATION WILL ADDRESS SIX TOPICS

1. ROLE OF THE PILOT STUDY
2. OPTIONS CONSIDERED
3. DECISION TREE COMPONENTS
   - DECISION SCENARIOS
     - COSTS AND BENEFITS CONSIDERED
     - PERFORMANCE MEASURES
   - UNCERTAINTIES
     - ASSESSED PROBABILITIES
     - CALCULATED PROBABILITIES
4. DECISION TREE ANALYSIS AND RESULTS
5. SENSITIVITY GRAPHS
6. CONCLUSIONS

THE PILOT STUDY HAD THREE MAJOR FUNCTIONS

1. TEST THE FEASIBILITY OF THE APPROACH

2. DETERMINE ELEMENTS OF METHODOLOGY LIKELY TO BE MOST SIGNIFICANT TO DETERMINING RESULTS

3. DEMONSTRATE WHAT ANALYSIS WILL INCLUDE AND TYPE OF OUTPUTS THAT COULD BE PRODUCED

FOUR REPRESENTATIVE (BUT HYPOTHETICAL) ESF OPTIONS WERE SPECIFIED FOR THE PILOT STUDY EVALUATION

OPTION 1

- 2 SHAFTS - DRILL AND BLAST CONSTRUCTION METHOD
- BASED ON SITE CHARACTERIZATION PLAN (SCP)
- REQUIRES MINIMUM AMOUNT OF REAL ESTATE FOR ESF

OPTION 2

- 1 RAMP, 1 SHAFT - DRILL AND BLAST CONSTRUCTION WITH TUNNEL BORING MACHINE AVAILABILITY
- PROVIDES MORE FLEXIBILITY IN ESF USES, VENTILATION, ETC.

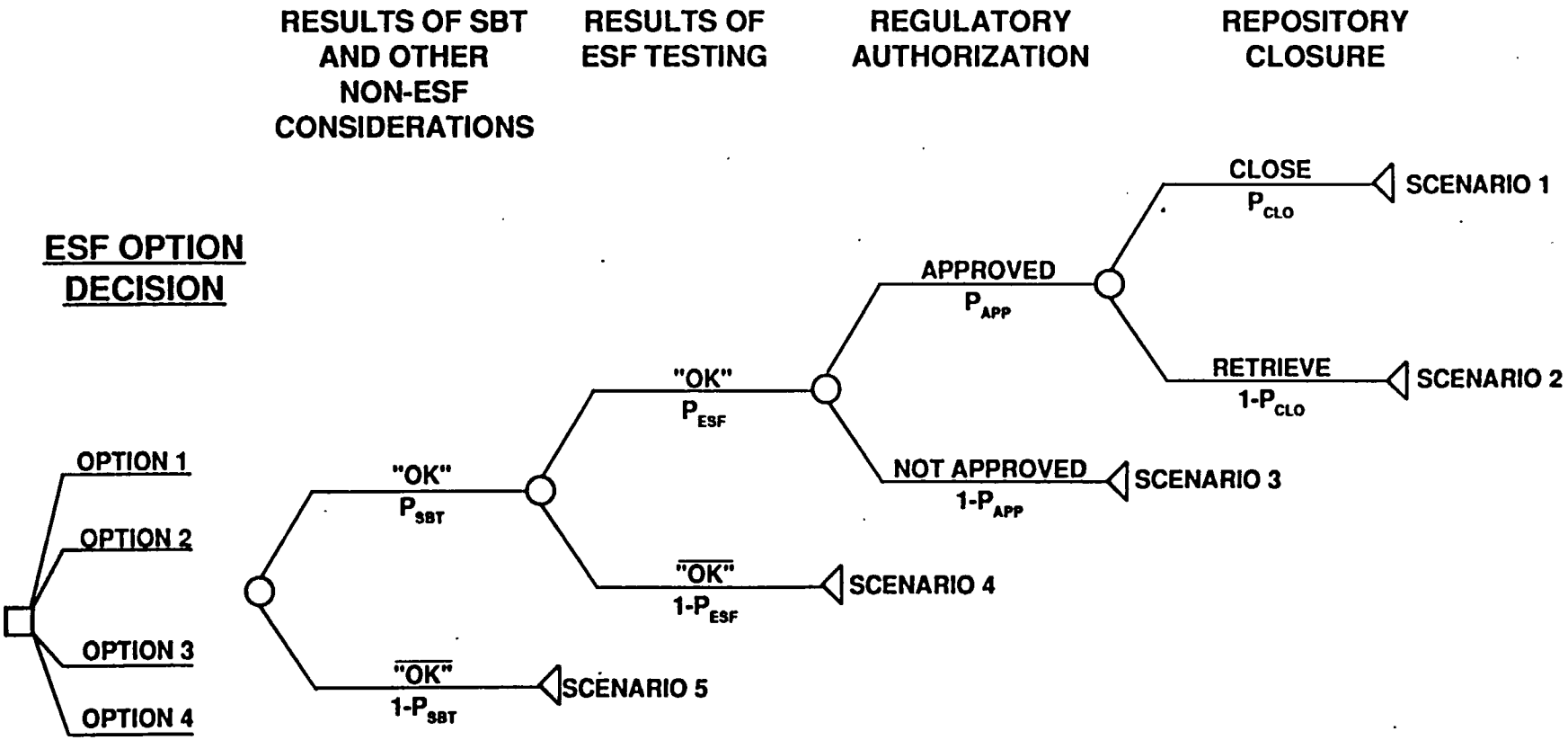
OPTION 3

- 1 RAMP ON NE, 1 SHAFT ON SW - TUNNEL BORING MACHINE FOR DRIFTS DRILL AND BLAST FOR EXCAVATION AND TEST AREA
- WASTE EMPLACEMENT ROOMS PERPENDICULAR TO MAIN AND CONFORMING TO GEOLOGY
- 5 OPENINGS: 2 RAMPS AND 3 SHAFTS

OPTION 4

- 1 RAMP ON NE - TUNNEL BORING MACHING
- 1 SHAFT ON NE - DRILL AND BLAST
- REPOSITORY CONSTRUCTED WITH TUNNEL BORING MACHINE
- REPOSITORY LAYOUT IN TWO PIECES

THE DECISION TREE SHOWS THE SUBSEQUENT DECISIONS AND EVENTS CONSIDERED IN THE PILOT STUDY



NEED TO DETERMINE:

- CONSEQUENCES OF EACH SCENARIO (1-5) AND THEIR UTILITIES
- PROBABILITIES FOR EACH UNCERTAINTY

THE FIVE SCENARIOS IN THE DECISION TREE HAVE DIFFERENT COSTS AND BENEFITS

SCENARIO	DESCRIPTION	CONSEQUENCES	
		SOCIAL COSTS (POTENTIAL ADVERSE IMPACTS ON HUMAN HEALTH, ENVIRONMENT, TEC.)	BENEFITS (EXTENT TO WHICH END GOALS ARE ACHIEVED)
1	CLOSURE	ESF, REPOSITORY, CLOSURE	PERMANENT REPOSITORY
2	RETRIEVAL	ESF, REPOSITORY, RETRIEVAL	WASTE AT YUCCA MOUNTAIN; NO REPOSITORY
3	ABANDONMENT	ESF	WASTE AT REACTORS; NO REPOSITORY
4	ABANDONMENT	ESF	WASTE AT REACTORS; NO REPOSITORY
5	ABANDONMENT	ESF	WASTE AT REACTORS; NO REPOSITORY

Note: "Costs" not explicitly included are the same for all options

EIGHT PERFORMANCE MEASURES WERE DEFINED FOR "COSTS"

"COSTS"		MEASURE/UNITS
PRECLOSURE		
1. WORKER HEALTH AND SAFETY	(X_1)	EXPECTED WORKER FATALITIES
2. ENVIRONMENT/AESTHETICS	(X_2)	VISIBILITY OF HEADFRAMES, DUST, EXHAUST PLUME
3. ENVIRONMENT/HISTORICAL PROPERTIES	(X_3)	ACRES IMPACTED
4. ENVIRONMENT/BIOLOGICAL IMPACTS	(X_4)	ACRES IMPACTED
5. SOCIOECONOMIC IMPACTS	(X_5)	PEAK NUMBER OF WORKERS
6. SCHEDULE DELAYS	(X_6)	MONTHS
7. DIRECT ECONOMIC COSTS	(X_7)	MILLIONS OF DOLLARS
POSTCLOSURE		
8. RADIONUCLIDE RELEASE	(X_8)	FRACTION OF EPA STANDARD

SIMPLIFIED CALCULATIONS YIELDED A ROUGH ESTIMATE FOR EACH PERFORMANCE MEASURE AND EACH SCENARIO

EXAMPLE:

ASSUME

0.55 STATISTICAL FATALITIES/10^6 MAN-HRS FOR D&B
0.275 STATISTICAL FATALITIES / 10^6 MAN-HRS FOR TBM

SOURCE: *DOE/RW-0074*

	ESF			REPOSITORY			RETRIEVAL		
	MAN-HOURS		EXP.	MAN-HOURS		EXP.		EXP. FATALITIES	EXP. FATALITIES
OPTION	D&B	TBM	FATALITIES	D&B	TBM	FATALITIES		ESF + REP	ESF + REP + RET
1	600,000	0	0.33	8,760,000	800,000	5.04		5.37	10.4 1
2	528,000	80,000	0.31	8,760,000	720,000	5.02	(SAME AS REPOSITORY)	5.33	10.35
3	528,000	16,000	0.33	0	4,640,000	1.28		1.61	2.89
4	504,000	176,000	0.33	0	4,640,000	1.28		1.61	2.89

VALUE JUDGMENTS TRANSLATED EACH PERFORMANCE MEASURE ESTIMATE TO AN EQUIVALENT ECONOMIC COST

EXAMPLE: WORKER

ASSUME 1 STATISTICAL WORKER FATALITY = $1M SOCIAL COST

OPTION	ESF		ESF + REP		ESF + REP + RET	
	EXP. FATALITIES	EQUIV. COST	EXP. FATALITIES	EQUIV. COST	EXP. FATALITIES	EQUIV. COST
1	.33	$.33M	5.37	$5.37M	10.41	$10.41M
2	.31	$.31M	5.33	$5.33M	10.35	$10.35M
3	.33	$.33M	1.61	$1.61M	2.89	$2.89M
4	.33	$.33M	1.61	$1.61M	2.89	$2.89M

CONSEQUENCE ESTIMATES FOR ESF OPTION 1

PERFORMANCE MEASURE		ESF (MEASURE)	ESF (EQUIV. COSTS $MILLIONS)	REPOSITORY (MEASURE)	REPOSITORY (EQUIV. COSTS $MILLIONS)	RETRIEVAL (MEASURE)	RETRIEVAL (EQUIV. COSTS $MILLIONS)
PRE-CLOSURE:							
HEALTH & SAFETY	(x1)	.33 FATALITIES	0.33	5.04 FATALITIES	5.04	5.04 FATALITIES	5.04
VISUAL AESTHETICS	(x2)						
HEADFRAME		0	0.00	0	0.00	0	0.00
DUST		0	0.00	0	0.00	0	0.00
EXHAUST PLUME		0	0.00	1	11.00	1	11.00
HISTORICAL PROPERTIES	(x3)	18 ACRES IMPACTED	1.20	69 ACRES IMPACTED	4.60	0 ACRES IMPACTED	0.00
BIOLOGICAL EFFECTS	(x4)	18 ACRES IMPACTED	0.78	69 ACRES IMPACTED	3.00	69 ACRES IMPACTED	3.00
SOCIO-ECONOMIC	(x5)	360 PEAK WORKERS	3.17	3,600 PEAK WORKERS	31.69	3,600 PEAK WORKERS	31.69
SCHEDULE COSTS	(x6)	125 MONTHS	750.00	468 MONTHS	2808.00	300 MONTHS	1800.00
DIRECT COSTS	(x7)	239	239.00	7,810	7,810.00	8,047	8,047.00
TOTAL PRE-CLOSURE COSTS:			994.48		10,673.33		9,897.73
POST-CLOSURE (Applicable only to closed repository with no retrieval)	(x8)			0.000117 fraction of EPA standard releases	0.33		

Total Costs of ESF and Abandonment (Scenarios 3,4,5)	=	994.48			=	994
Total Costs of Closed Repository (Scenario 2)	=	994.48	+ 10,673.33	+ 0.33	=	11,668
Total Costs of Retrieved Repository (Scenario 1)	=	994.48	+ 10,673.33	+ 9,897.73	=	21,566

DECISION TREE UNCERTAINTIES, POSSIBLE OUTCOMES, AND PROBABILITIES

UNCERTAINTIES	POSSIBLE OUTCOMES		PROBABILITIES	
* SURFACE-BASED TESTING	"OK"	"$\overline{\text{OK}}$"	P_{SBT}	$1-P_{SBT}$
* ESF TESTING	"OK"	"$\overline{\text{OK}}$"	P_{ESF}	$1-P_{ESF}$
** REGULATORY AUTHORIZATION	APPROVED	NOT APPROVED	P_{APP}	$1-P_{APP}$
REPOSITORY CLOSURE	CLOSED	RETRIEVED	P_{CLO}	$1-P_{CLO}$

* FAVORABLE SBT AND ESF TEST RESULTS LEAD TO A LICENSE APPLICATION
** APPROVAL OF LICENSE APPLICATION LEADS TO CONSTRUCTION OF THE REPOSITORY

TWO OF THE PROBABILITIES WERE ASSUMED NOT TO VARY AMONG THE FOUR OPTIONS

P_{SBT} = PROBABILITY THAT SURFACE-BASED TESTING RESULTS ARE "OK"

P_{CLO} = PROBABILITY OF A SUCCESSFULLY CLOSED REPOSITORY, GIVEN LICENSE APPROVAL

ASSESSED PROBABILITIES:

$P_{SBT} = 0.90$

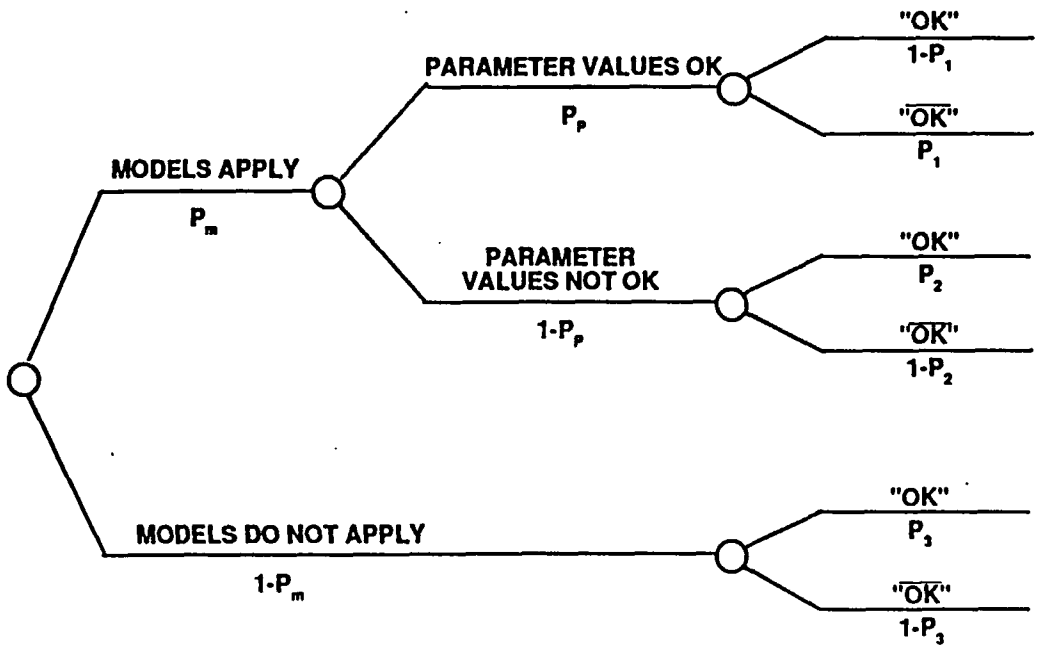
$P_{CLO} = 0.99$

TO FIND THE PROBABILITY THAT THE OUTCOME OF ESF TESTING IS "OK" (P_{ESF}), WE NEED TO EXAMINE "NATURE'S TREE"

ACTUAL CONDITIONS	SITE CHARACTERIZATION TEST OUTCOME	DESCRIPTION

DO MODELS CONFORM TO SITE?

ARE MODEL PARAMETERS WITHIN ACCEPTABLE REGION?



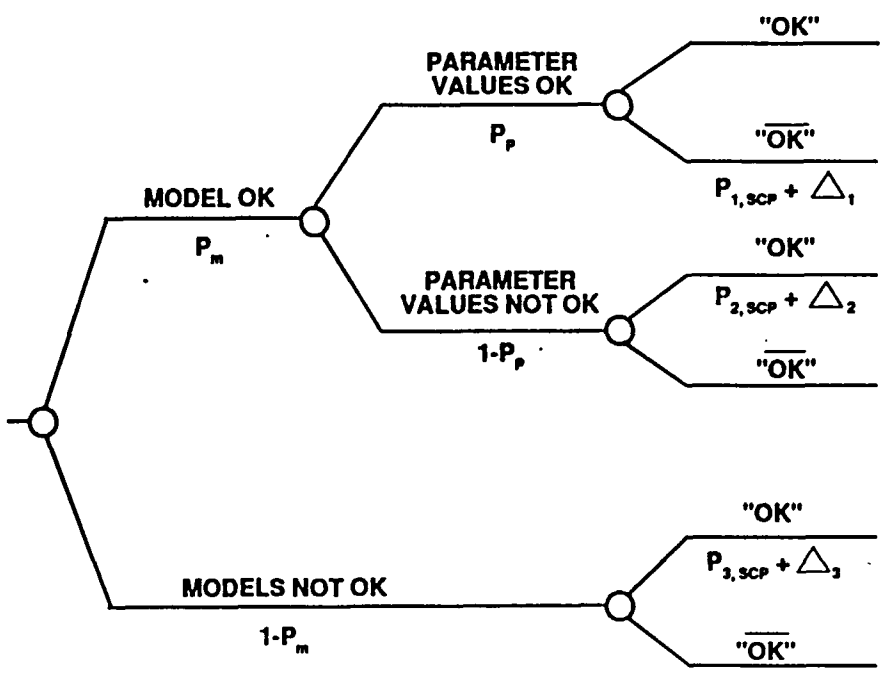
1. TESTING CORRECTLY IDENTIFIES ACCEPTABLE PARAMETER VALUES AS ACCEPTABLE
2. TESTING INCORRECTLY REJECTS ACCEPTABLE SITE
3. TESTING INCORRECTLY IDENTIFIES UNACCEPTABLE PARAMETER VALUES AS ACCEPTABE
4. TESTING CORRECTLY IDENTIFIES UNACCEPTABLE PARAMETER VALUES AS UNACCEPTABLE
5. TESTING INCORRECTLY IMPLIES ACCEPTABLE SITE WHEN MODELS DO NOT APPLY
6. TESTING CORRECTLY IMPLIES AN UNACCEPTABLE SITE DUE TO BAD MODELS OR PARAMETERS

P_1, P_2, AND P_3 ARE THE PROBABILITIES THAT TESTING YIELDS THE INCORRECT RESULT

EACH OPTION IS COMPARED TO THE SCP TO DETERMINE P_1, P_2, AND P_3

FOR EACH OPTION: $P_i = P_{i,SCP} + \Delta_i$

TO ASSESS Δ_i : $\Delta_i = \begin{cases} 0.1 & \text{MUCH WORSE THAN SCP} \\ 0 & \text{ABOUT THE SAME AS SCP} \\ -0.1 & \text{MUCH BETTER THAN SCP} \end{cases}$

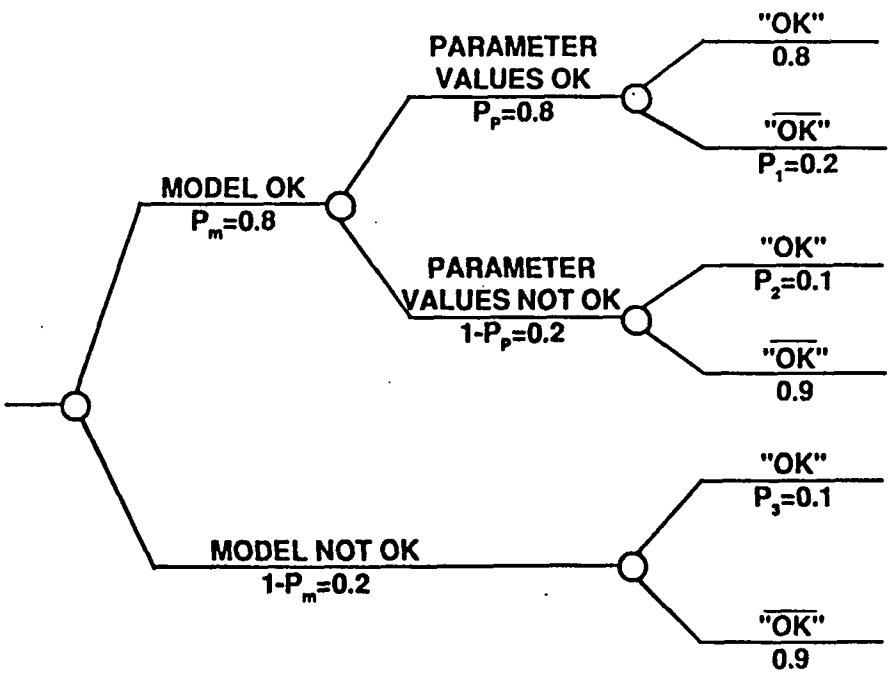


i	$P_{i,SCP}$	ASSESSED VALUES: OPT 1	OPT 2	OPT 3	OPT 4
1	0.2	0	-0.10	-0.15	-0.12
2	0.1	0	-0.05	-0.07	-0.06
3	0.1	0	-0.03	-0.03	-0.03

ASSESSED AND CALCULATED PROBABILITIES ARE NEEDED TO DETERMINE P_{ESF}

DESCRIPTION	SYMBOL	VALUE
PROB { MODEL OK}	P_m	0.8
PROB { PARAM. VALUES OK / MODEL OK }	P_p	0.8
PROB { TEST SAYS "OK" / MODEL & PARAM. VALUES ARE OK }	P { "OK" / OK }	0.8

EXAMPLE: NATURE'S TREE FOR OPTION 1



PATH PROBABILITY	CALCULATED PROBABILITIES	
0.512	0.512	0.512
0.128		0.128
0.016	0.16	
0.144		
0.020	0.20	
0.180	+	+
	0.55	0.64

P_{ESF} = Prob {TEST SAYS "OK"}= 0.55

Prob {site is OK} = 0.64

BAYES' RULE MAY BE USED TO DETERMINE THE PROBABILITY THAT THE SITE IS REALLY OK IF THE TEST SAYS "OK"

$$P\{OK / \text{"OK"}\} = \frac{P\{OK\} \quad P\{\text{"OK"} / OK\}}{P\{\text{"OK"}\}}$$

P {OK / "OK"} CAN BE CONSIDERED WHEN ASSESSING P_{APP}, TOGETHER WITH:

- REGULATORY COMPLIANCE
- ESTIMATED REPOSITORY CONSEQUENCES

PROBABILITY THAT THE SITE IS NOT OK IF THE TEST SAYS "OK"

OPTION	P[OK] (MODELS + PARAMETERS BOTH OK)	P["OK" / OK] (TEST SAYS OK IF SITE IS OK)	P["OK"] (TEST SAYS OK)	P[OK / "OK"]	P[$\overline{OK}$ / "OK"] ↓
1	0.64	0.80	0.55	0.93	0.07
2	0.64	0.90	0.60	0.96	0.04
3	0.64	0.95	0.63	0.97	0.03
4	0.64	0.92	0.61	0.97	0.03

NOTE: P[$\overline{OK}$ / "OK"] = 1 - P[OK / "OK"]

P_{APP}, THE PROBABILITY OF LICENSE APPROVAL, IS THE FINAL PROBABILITY NEEDED

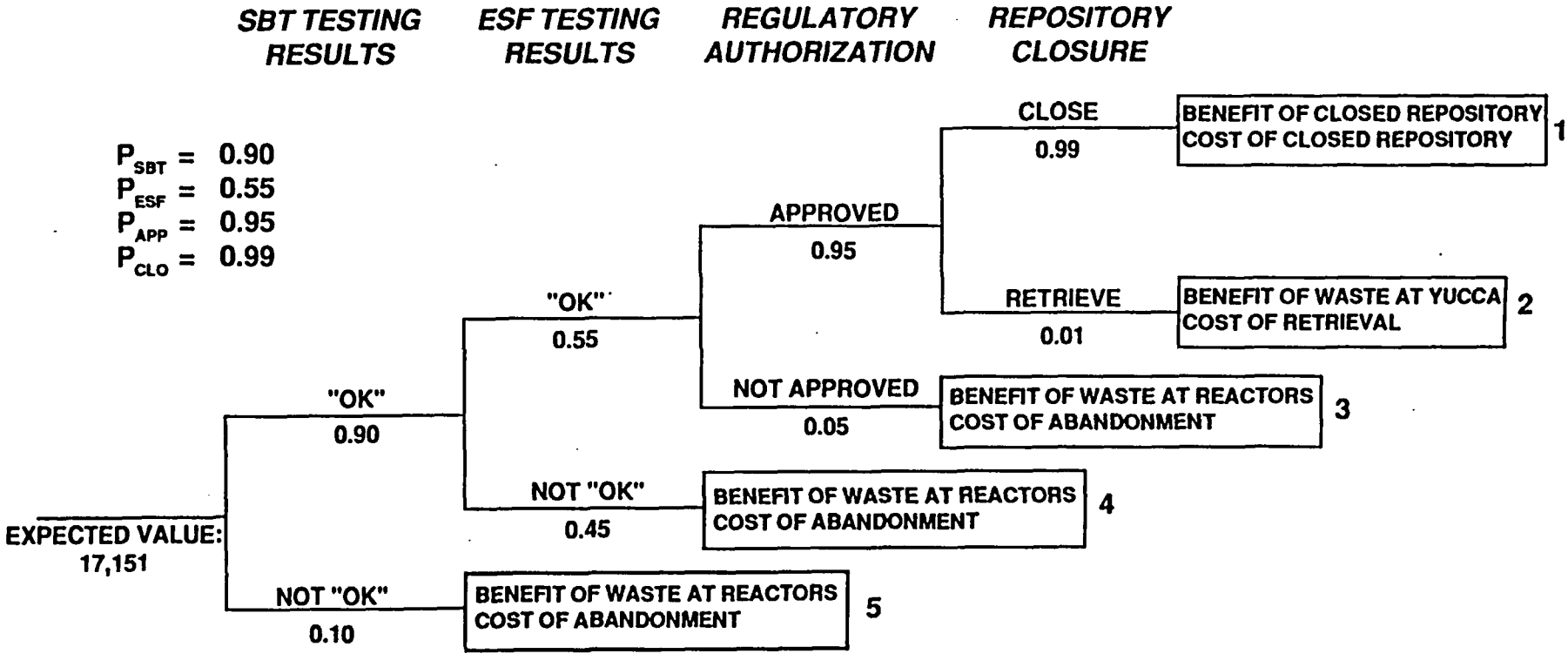
IN THE PILOT STUDY, P_{APP} IS ESTIMATED BY COMPARISON TO THE BASE CASE (OPTION 1):

OPTION	1	2	3	4
P_{APP}	0.95	0.97	0.98	0.97

SUMMARY OF TREE PROBABILITIES

OPTION	PROB {SBT TEST SAYS "OK"} $*P_{SBT}$	PROB {ESF TEST SAYS "OK} $**P_{ESF}$	PROB {APPROVAL} $*P_{APP}$	PROB {CLOSED REPOSITORY, GIVEN TESTS ARE "OK" AND LICENSE IS APPROVED} $*P_{CLO}$	PROBABILITY OF SUCCESSFUL CLOSURE (SCENARIO 1) **
1	0.90	0.55	0.95	0.99	0.466
2	0.90	0.60	0.97	0.99	0.519
3	0.90	0.63	0.98	0.99	0.550
4	0.90	0.61	0.97	0.99	0.527

DECISION TREE FOR OPTION 1



COSTS		($M)
COST OF ABANDONMENT	=	994
COST OF CLOSED REPOSITORY	=	11,668
COST OF RETRIEVAL	=	21,566
EXPECTED COST:		6,042

BENEFITS		($M)
BENEFIT OF WASTE AT REACTORS [O]	=	0
BENEFIT OF CLOSED REPOSITORY [K]	=	50,000
BENEFIT OF WASTE AT YUCCA [A]	=	0
EXPECTED BENEFIT:		23,193

A SENSITIVITY ANALYSIS WAS PERFORMED

THE FOLLOWING VARIABLES WERE EXAMINED:

K	-	BENEFITS OF CLOSED REPOSITORY
A	-	VALUE OF WASTE AT YUCCA MOUNTAIN RELATIVE TO WASTE AT REACTORS
P_{SBT}	-	PROBABILITY THAT SBT RESULTS ARE "OK"
P_{APP}	-	PROBABILITY OF LICENSE APPROVAL
P_{CLO}	-	PROBABILITY OF CLOSED REPOSITORY, GIVEN LICENSE APROVAL

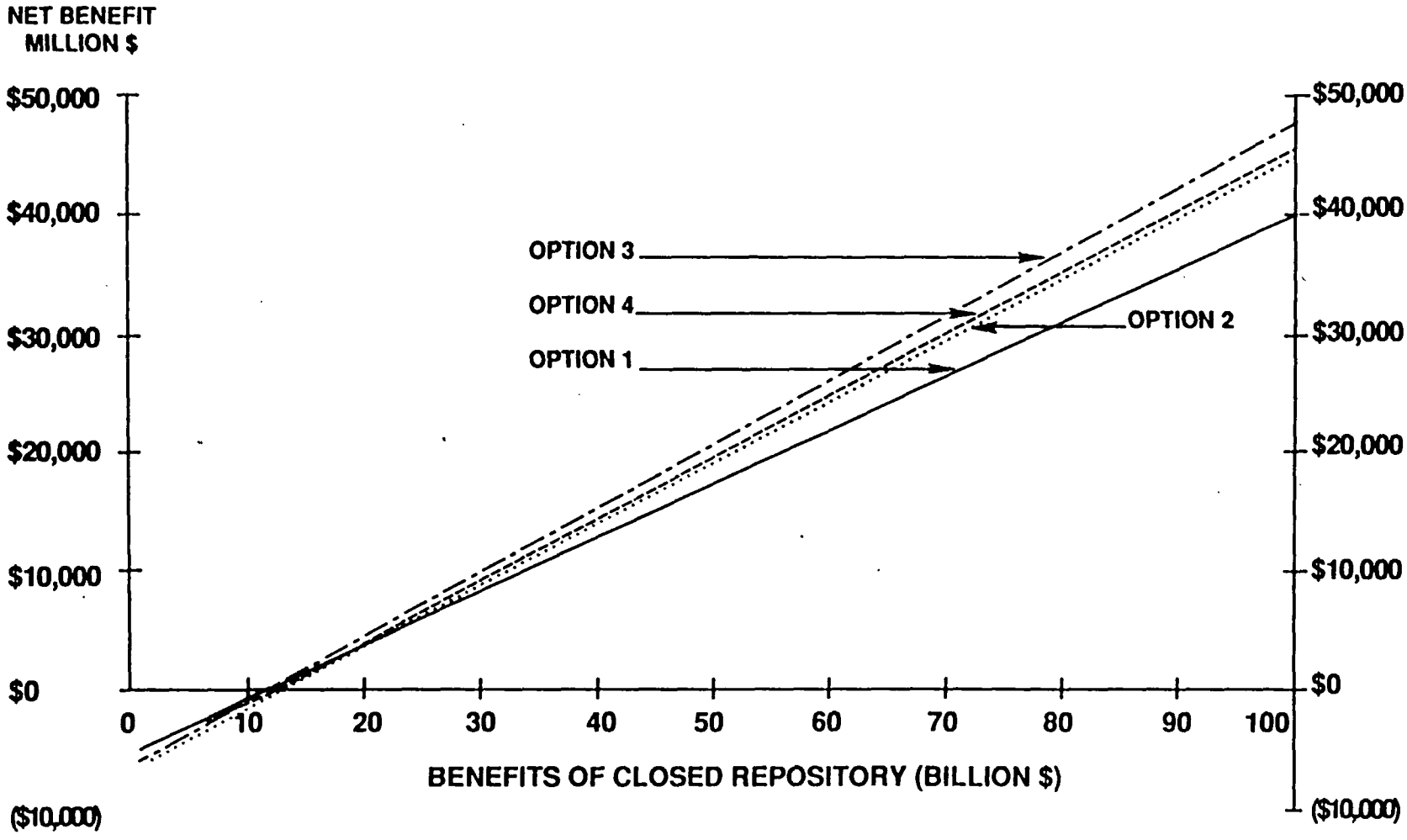
FOR EACH ANALYSIS, ALL OTHER VARIABLES WERE KEPT AT THEIR NOMINAL VALUES (SEE DECISION TREES)

RANKING OF OPTIONS BASED ON SPECIFIC CRITERIA

(ASSUMES A CLOSED REPOSITORY)

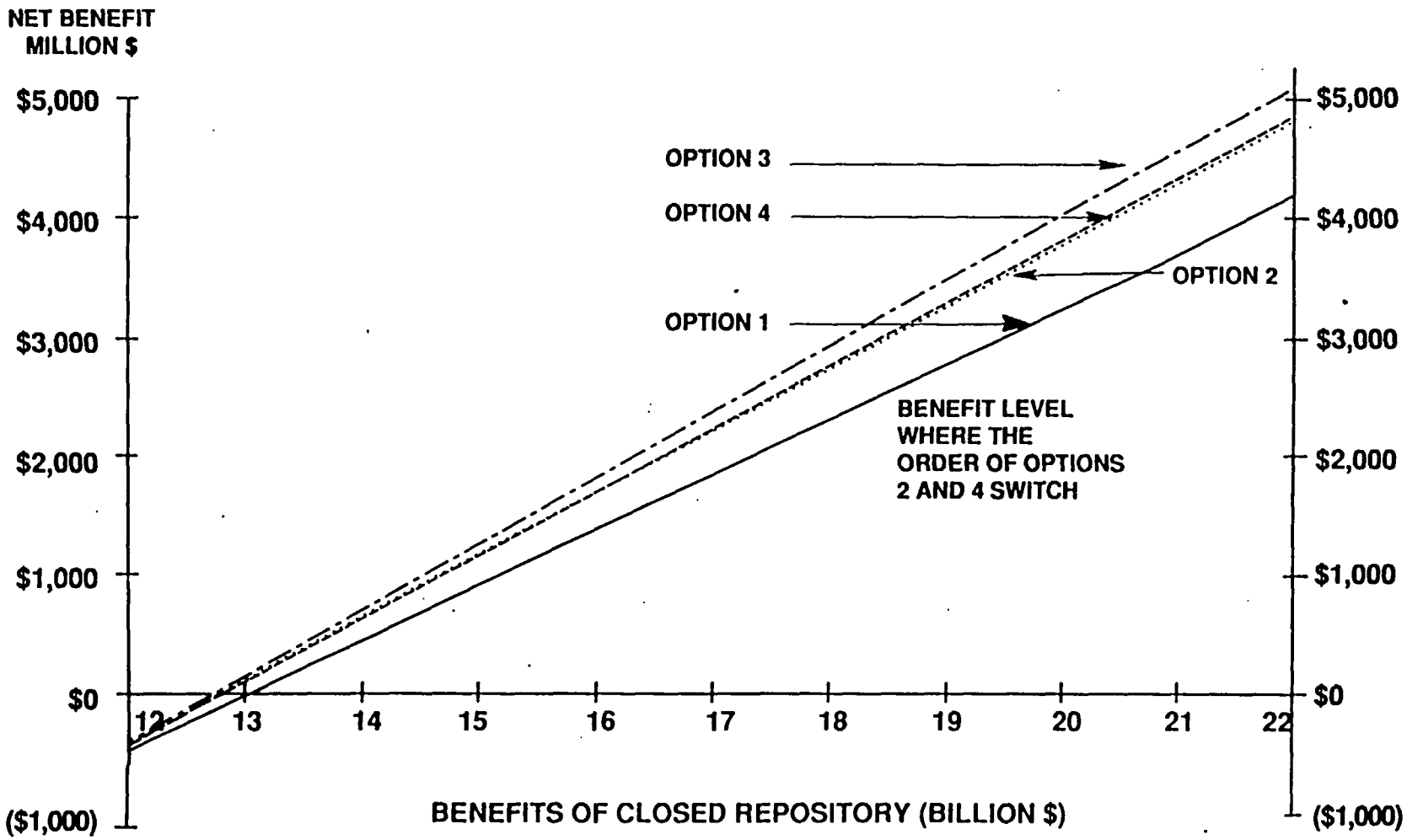
Option	Postclosure Releases x_8	Worker Health & Safety x_1	Environ-mental $x_2 - x_4$	Socio-economic x_5	Total Non-Economic Costs $x_1 - x_5, x_8$	Direct And Schedule Costs x_{6-7}	Total Costs Including Schedule & Economic Costs $x_1 - x_8$	Total Costs and Benefits	Probability of Obtaining a a Closed Repository
1	3rd	3rd	1st	2nd	2nd	2nd	2nd	4th	0.47
2	2nd	2nd	2nd	2nd	3rd	1st	1st	3rd	0.52
3	2nd	1st	4th	1st	4th	3rd	4th	1st	0.55
4	1st	1st	3rd	1st	1st	4th	3rd	2nd	0.53

SENSITIVITY TO VALUE OF CLOSED REPOSITORY

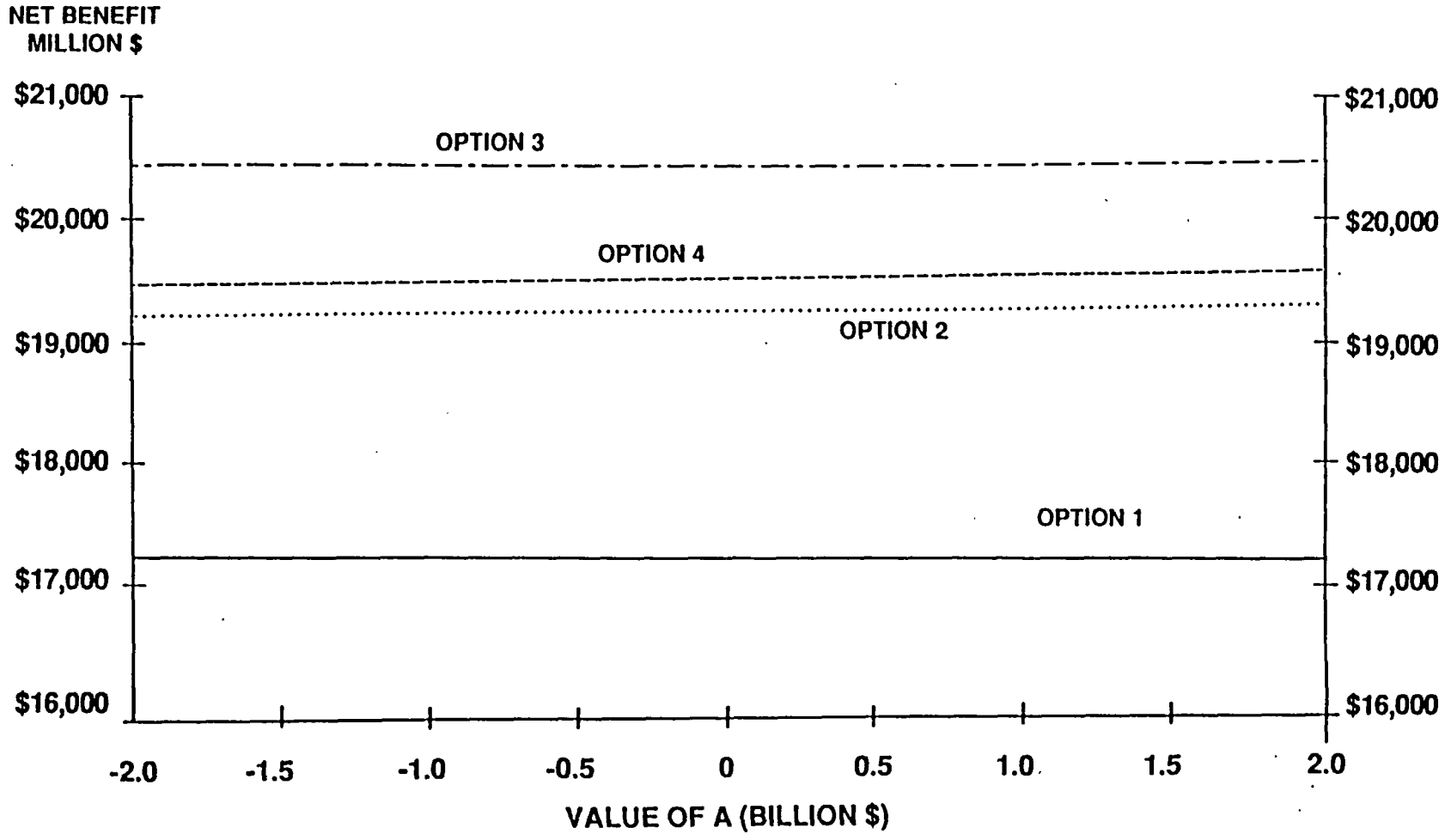


SENSITIVITY TO VALUE OF CLOSED REPOSITORY

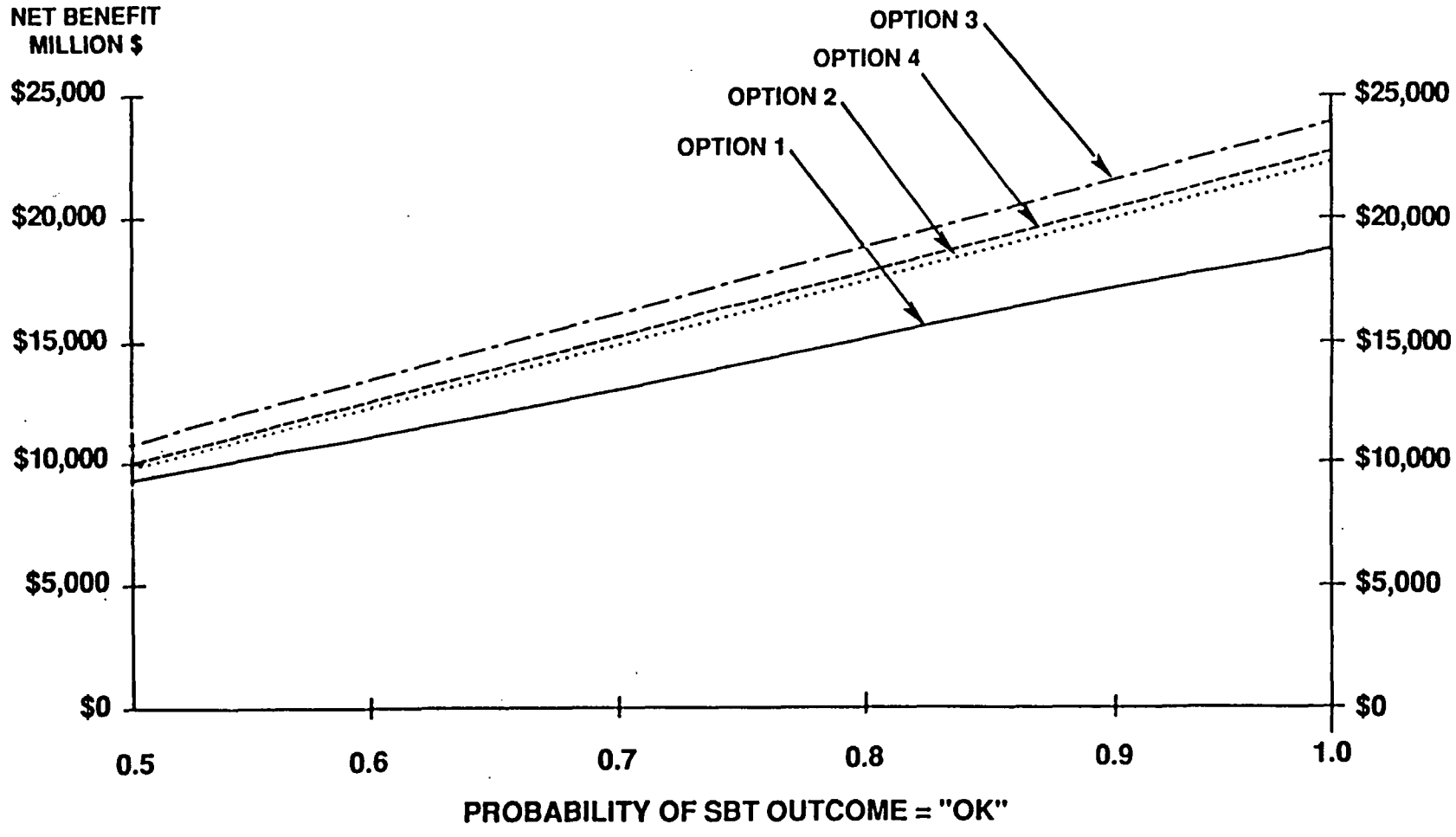
(BETWEEN 12 AND 22 BILLION $)



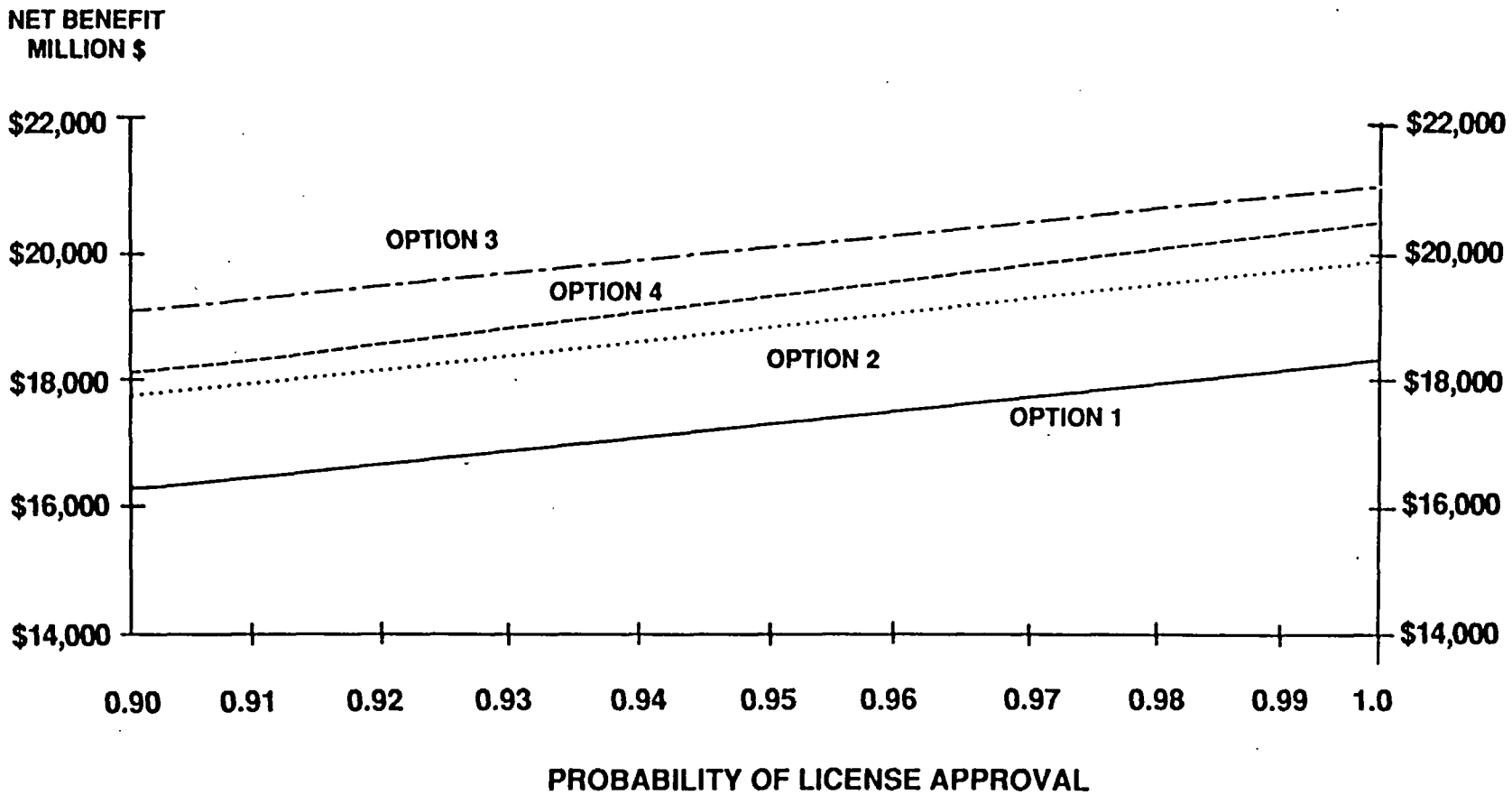
SENSITIVITY TO VALUE OF WASTE AT YUCCA RELATIVE TO WASTE AT REACTORS (A)



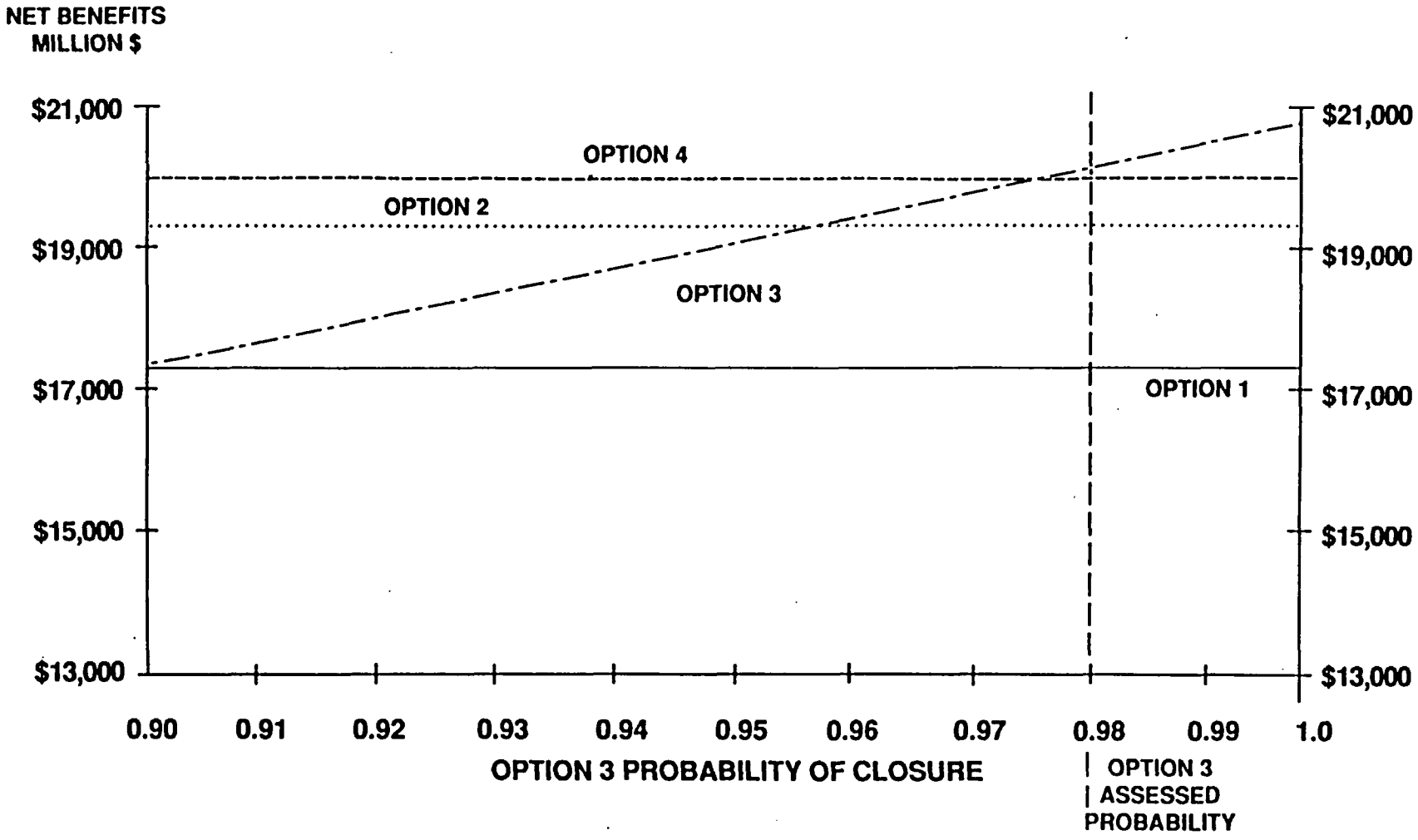
SENSITIVITY TO PROBABILITY OF SBT OUTCOME



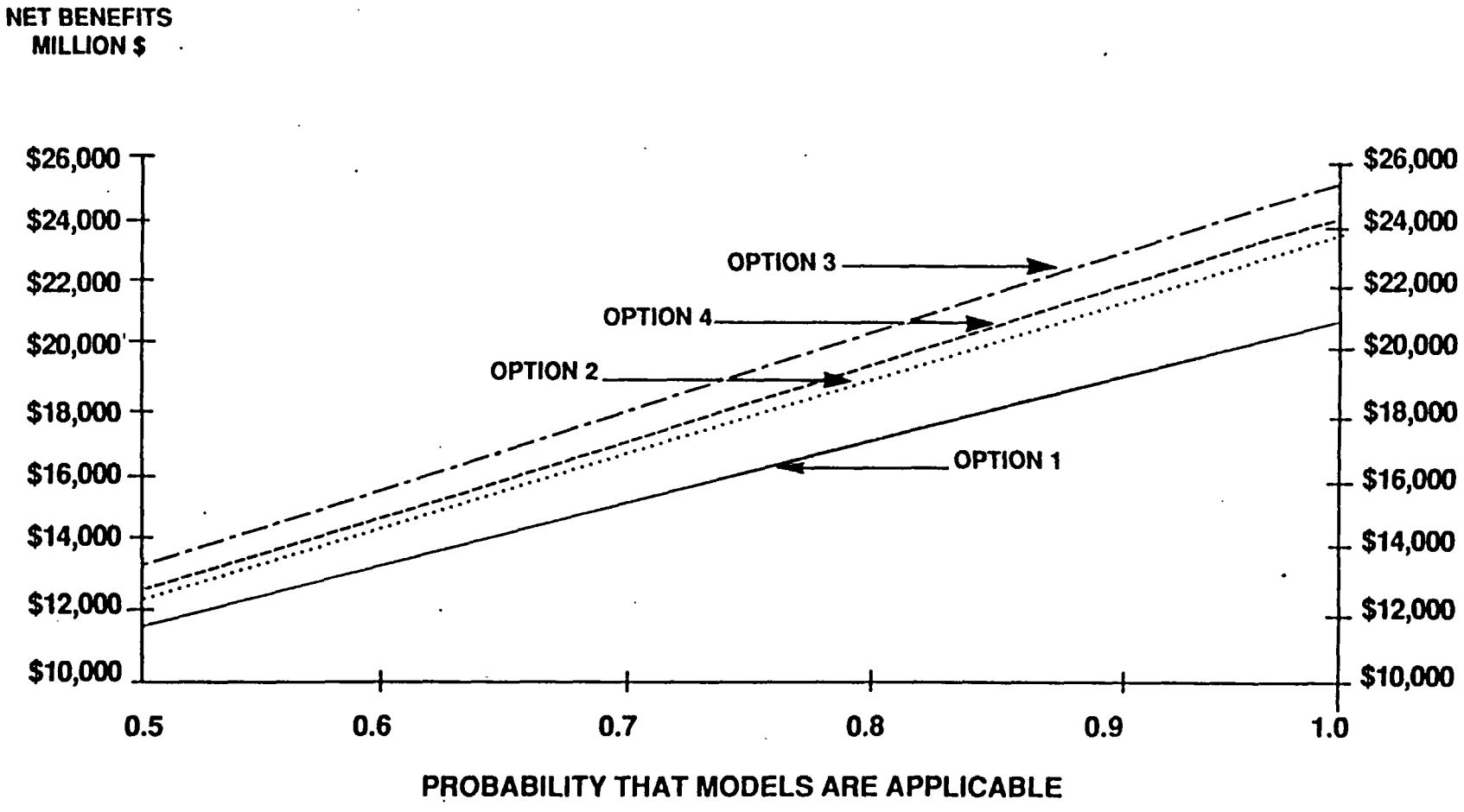
SENSITIVITY TO PROBABILITY OF LICENSE OUTCOME



SENSITIVITY TO PROBABILITY OF REPOSITORY CLOSURE



SENSITIVITY TO PROBABILITY OF MODEL APPLICABILITY



CONCLUSIONS

- THE SELECTED METHODOLOGY WAS CONCLUDED TO BE FEASIBLE AND POTENTIALLY ACCEPTABLE, SUBJECT TO SEVERAL IDENTIFIED REVISIONS

- THE RANKING OF OPTIONS IS BASICALLY THE SAME FOR ALL VALUES OF K (BENEFIT OF CLOSED REPOSITORY) LARGE ENOUGH TO MOTIVATE BUILDING A REPOSIOTRY

- RANKING OF OPTIONS IS INSENSITIVE TO
  - PROBABILITIES OF SBT RESULTS
  - PROBABILITIES OF CLOSURE vs RETRIEVAL
  - INCREMENTAL VALUE OF HAVING WASTE AT YUCCA MOUNTAIN vs AT REACTORS

- RANKING OF OPTIONS IS MOST SENSITIVE TO IMPACT OF ESF OPTION ON
  - TESTING ACCURACY
  - LIKELIHOOD OF REGULATORY APPROVAL