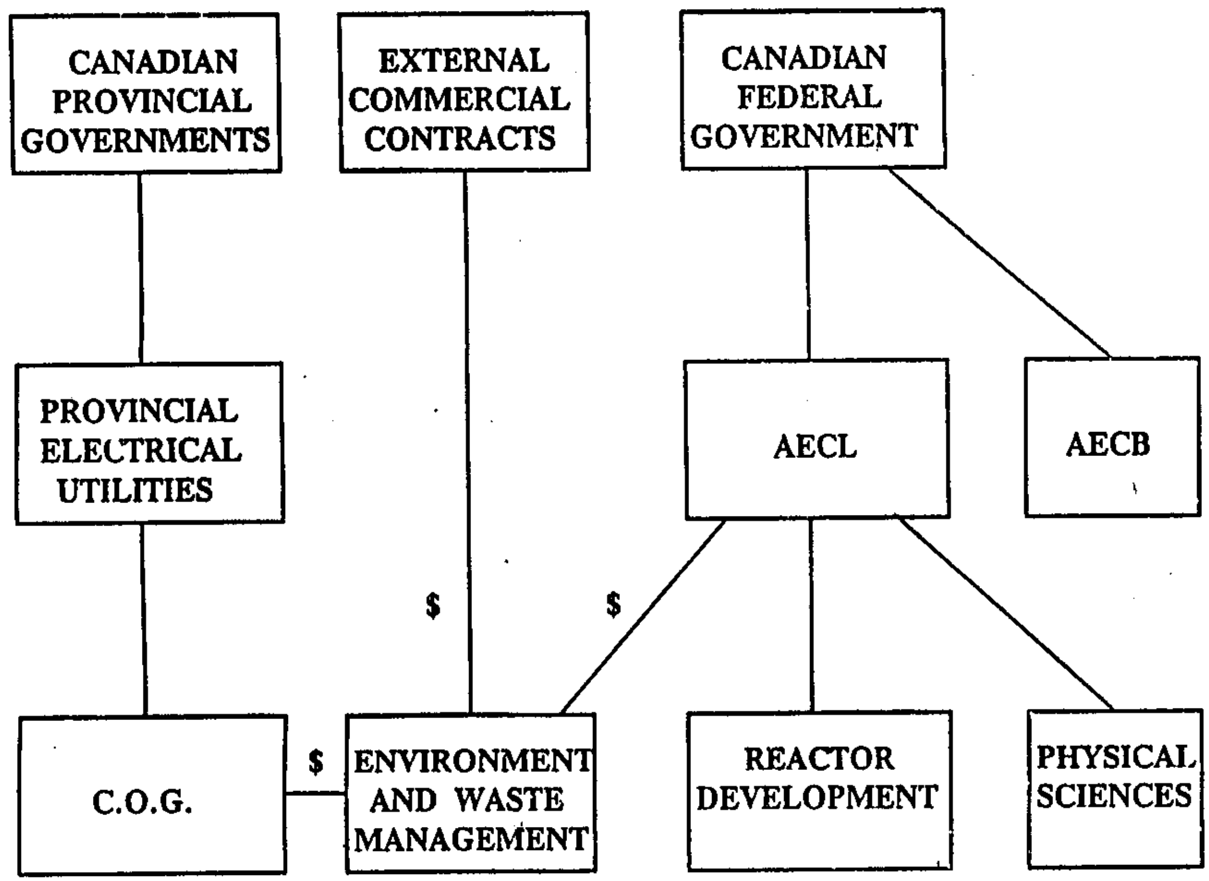
# Section 1

# Introduction

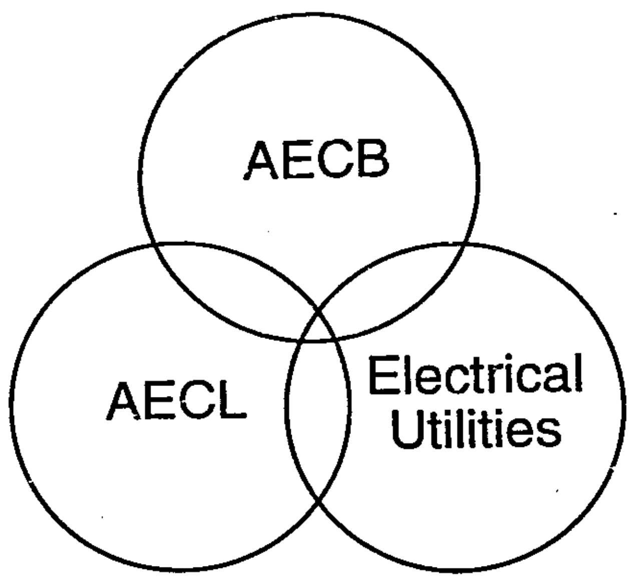
# and

# Systems Variabilty Analysis


CANADIAN PROVINCIAL GOVERNMENTS
EXTERNAL COMMERCIAL CONTRACTS
CANADIAN FEDERAL GOVERNMENT
PROVINCIAL ELECTRICAL UTILITIES
AECL
AECB
$
$
$
C.O.G.
ENVIRONMENT AND WASTE MANAGEMENT
REACTOR DEVELOPMENT
PHYSICAL SCIENCES

# RADWASTE Management in Canada

Regulatory Agency

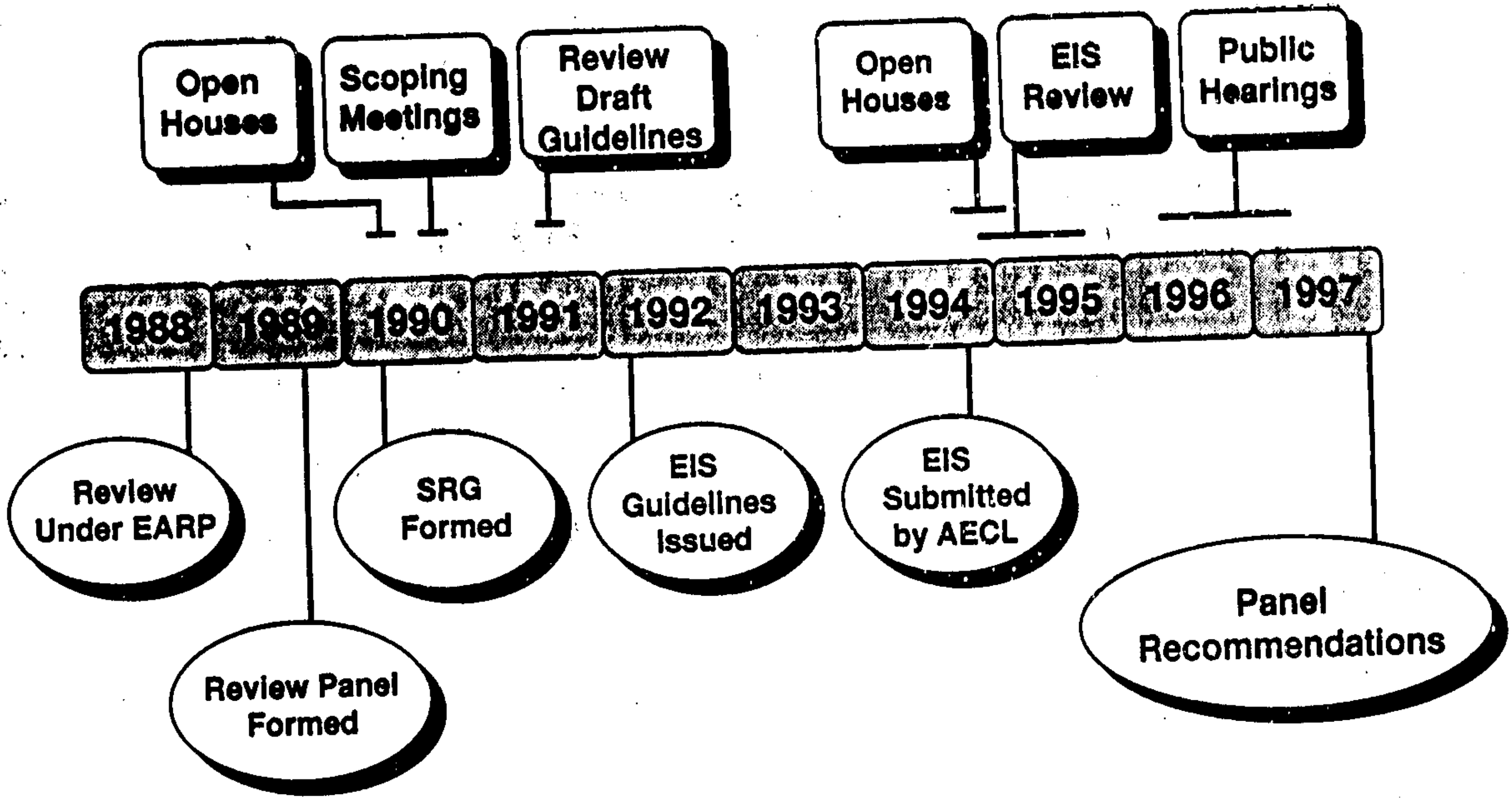



Design & Engineering
Research & Development

Nuclear Power Producers

- Ontario Hydro
- Hydro Quebec
- New Brunswick Power

# Environmental Review



# AECB Regulatory Documents

## Regulatory Policy Statement R-71

**Requirements for concept assessment**

## Regulatory Guide R-72

**Considerations in siting a repository**

## Regulatory Policy Statement R-85

**De minimis dose criterion**

## Regulatory Policy Statement R-104

**Requirements and guidelines for disposal**

# R-71: Deep Geological Disposal of Nuclear Fuel Waste: Background Information and Regulatory Requirements regarding the Concept Assessment Phase

- Defines regulatory roles and responsibilities and review process

- Defines general requirements of a disposal system e.g.,
  - meet regulatory criteria (pre-closure, post-closure)
  - no dependence on future generations
  - use multiple barriers
  - accommodate natural disturbances

- Defines general requirements for concept assessment and its documentation, e.g.,
  - demonstrate technical feasibility
  - calculate effective dose to public
  - address environmental impacts

- Defines requirements for analysis of performance, e.g.,
  - include all relevent events and processes
  - identify all assumptions
  - justify all data
  - QA of computer models

# R-72: Geological Considerations in Siting a Repository for Underground Disposal of High Level Radioactive Wastes

**Defines characteristics of a geologically acceptable site**

- **host geology must retard radionuclides**
- **little likelihood of exploitation of rock**
- **located in a geological stable region**
- **capable of withstanding stresses**
- **dimensions of host rock adequate**

# R-85: Radiation Protection Requisites for the Exemption of Certain Radioactive Materials from Further Licensing Upon Transferral for Disposal

- Defines eligibility for exemption from licensing and control
  - individual dose rate < 0.05 mSv/a (Deminimis Level)
  - localized radiological impact
  - small potential for exposure of large populations
  - decision on a case-by-case basis

# R-104: Regulatory Objectives, Requirements and Guidelines for the Disposal of Radioactives Wastes - Long Term Aspects

| | |
|---|---|
| Individual Risk | $< 10^{-6}$ per year |
| Time Scale | 10,000 years |
| Risk Conversion Factor | 0.02 per sievert |

**Predictive models and simulation codes require:**

- quality assurance
- validation
- peer review
- intercomparison

# OBJECTIVES OF RADIOACTIVE WASTE DISPOSAL

- Minimize any burden on future generations
- Protect the environment
- Protect human health

taking into account social and economic factors

# BURDEN ON FUTURE GENERATIONS

**shall be minimized by**

- **selecting disposal options which to the extent reasonably achievable do not rely on long-term institutional controls as a necessary safety feature**

- **implementing these disposal options at an appropriate time, technical, social and economic factors being taken into account**

- **ensuring that there are no predicted future risks to human health and the environment that would not be currently accepted**

# PROTECTION OF THE ENVIRONMENT

- **No predicted future impacts on the environment that would not be currently accepted**

- **Future use of natural resources is not prevented by contaminants**

# PROTECTION OF HUMAN HEALTH

## General Requirement

**Predicted radiological risk < $10^{-6}$ per year**

## Risk

**The probability that a fatal cancer or serious genetic effect will occur to an individual or his or her descendants**

# RADIOLOGICAL RISK

**The sum over all significant scenarios of**

**(probability of the scenario)**

**X**

**(the magnitude of the resultant dose)**

**X**

**(probability of a health effect per unit dose)**

**The last factor is given as 0.02 per sievert**

# GUIDELINE

# PROBABILITIES OF EXPOSURE SCENARIOS

## Relative frequency of occurence

## Best estimates and engineering judgements

# DEALING WITH UNCERTAINTY

- Multiple Barriers / Redundancy

- Conservative Regulations

- Conservative Assumptions

- Probabilistic Analysis

# SYVAC

## SYSTEMS VARIABILITY ANALYSIS CODE

## A PROBABILISTIC ASSESSMENT TOOL

# DATA CHARACTERISTICS

- supplied as PDFs by experts
- defensible
- upper and lower bounds
- correlated

# Modelling and R&D

- must maintain a strong link for credibility
- the “experts” must support the modelling
- the “experts” must support the choice of data

# OTHER SVA CODES

| | | |
|---|---|---|
| **LISA** | **-** | **Andy Saltelli, JRC (Ispra), Italy** |
| **EMOS** | **-** | **Alex Nies, GSF, Germany** |
| **PROPER** | **-** | **Nils Kjellbert, SKB, Sweden** |
| **VANDAL** | **-** | **Brian Thompson, DOE, U.K.** |
| **MASCOT** | **-** | **Jim Sinclair, AERE (Harwell), U.K.** |

# SYSTEMS VARIABILITY ANALYSIS

## A Method of Dealing With Uncertain Systems

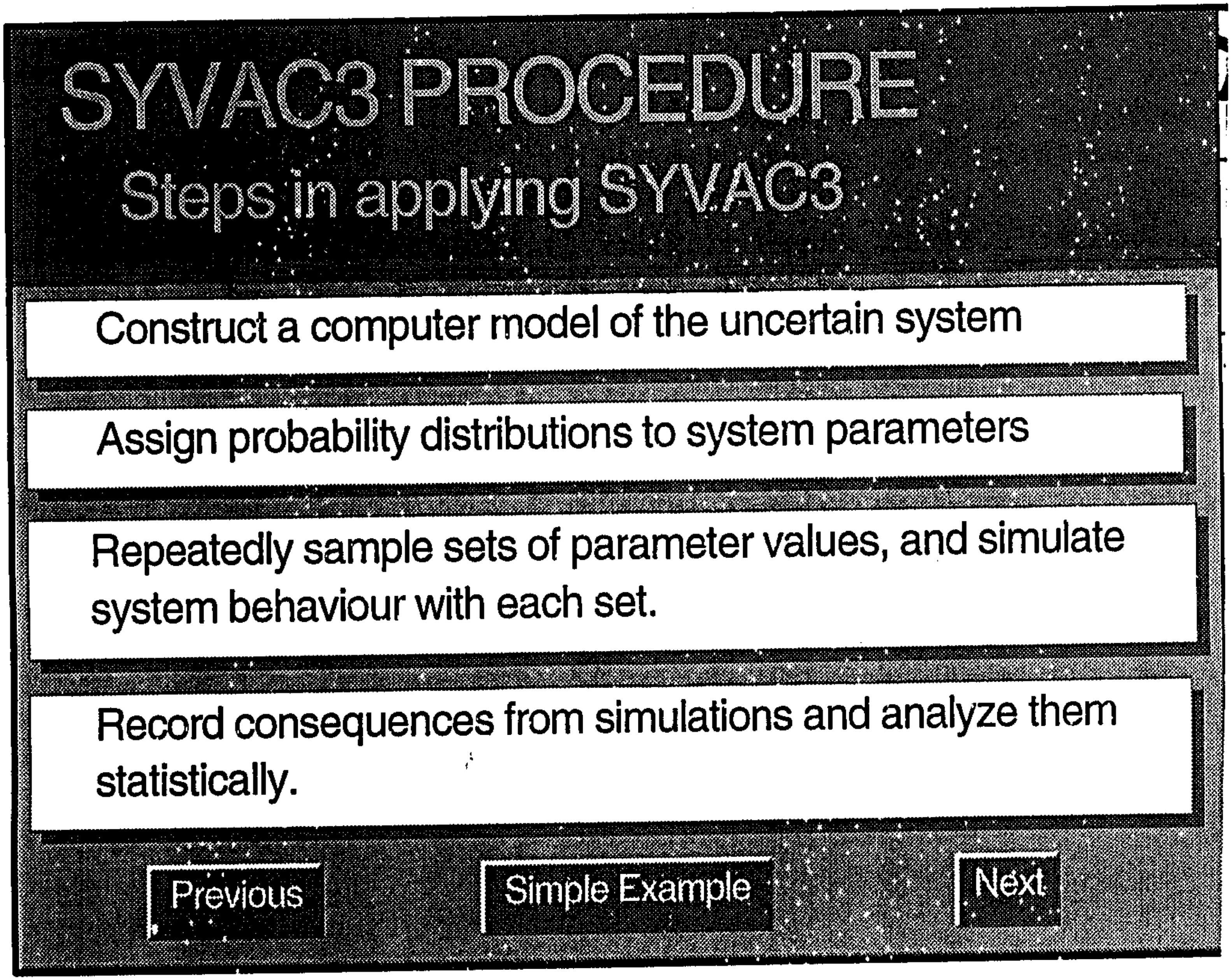
Definite System:

- Characteristics are known accurately
- Behaviour with time is well-established
- Quantitative properties can be measured

Uncertain System:

- Characteristics are known approximately
- Behaviour with time is estimated
- Quantitative properties vary from place to place

Previous Next



SYVAC3 PROCEDURE
Steps in applying SYVAC3
Construct a computer model of the uncertain system
Assign probability distributions to system parameters
Repeatedly sample sets of parameter values, and simulate system behaviour with each set.
Record consequences from simulations and analyze them statistically.
Previous
Simple Example
Next

# VARIABILITY ANALYSIS

## Uncertainty in PDF'S

- pdf's refect uncertainty in parameter values. pdf's are specified such that values of input parameters that are assumed to give predictions near to the eventual value are sampled more frequently. Where there is some doubt, the specification is made to overpredict consequence.

# VARIABILITY ANALYSIS

## Uncertainty in Models

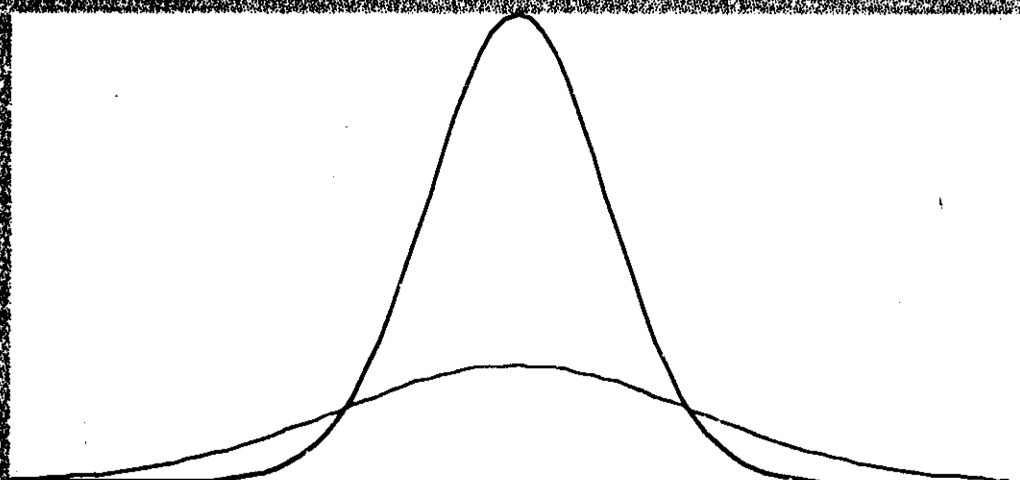
- modelling assumptions and limitations are used that would lead to overprediction of consequence

- modelling assumptions, limitations and uncertainty in specification of pdf's give rise to residual uncertainty

Previous Next Index

# VARIABILITY ANALYSIS

## Input Distributions

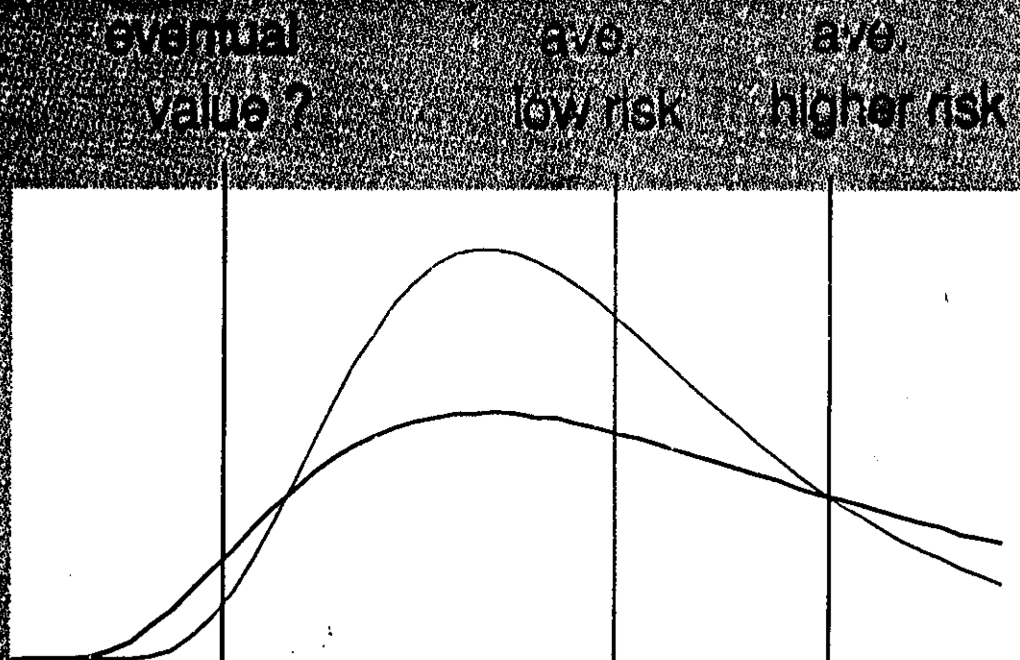


Input distributions

Previous Next Index

# VARIABILITY ANALYSIS

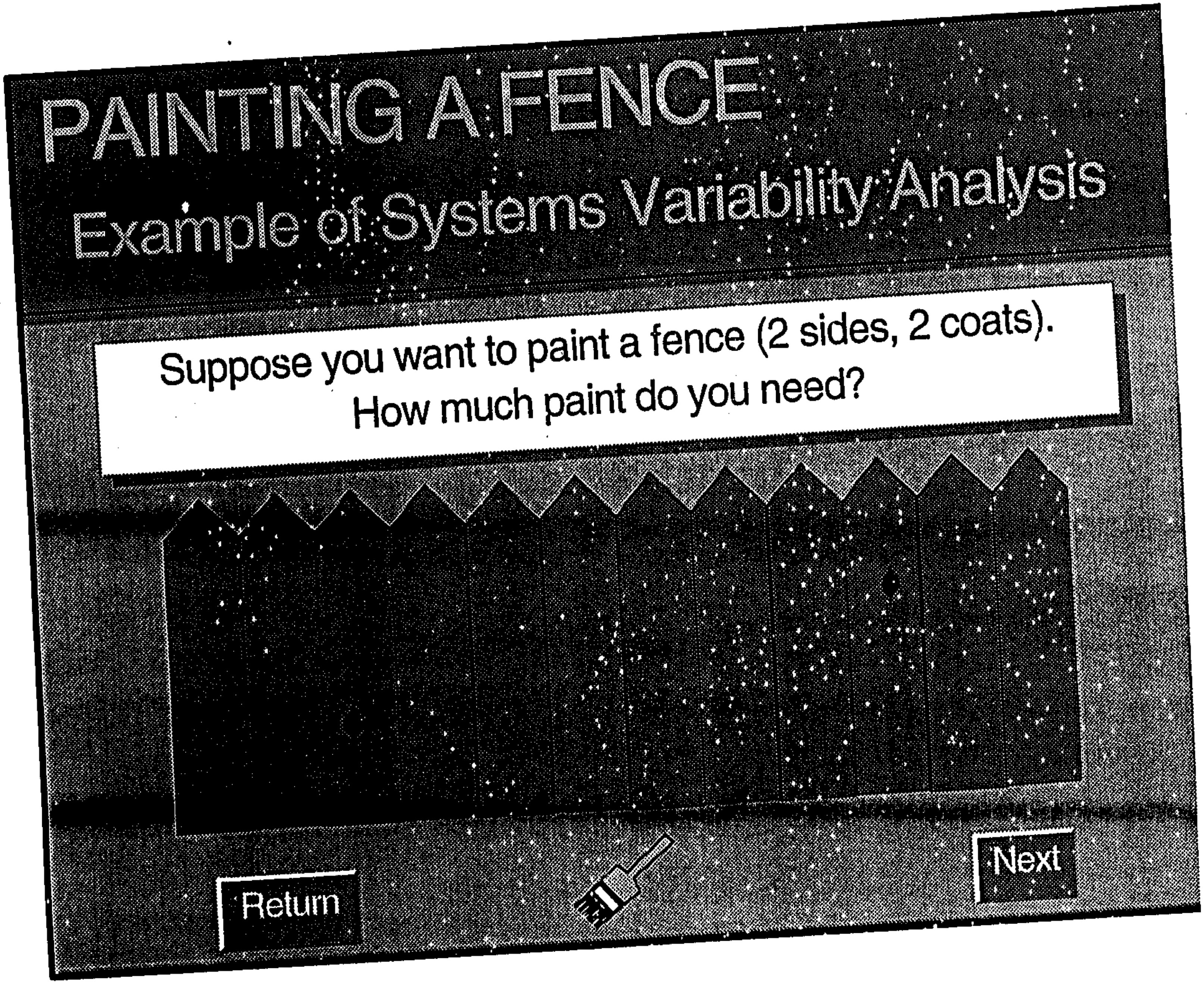
## Consequence




Previous

consequence distribution

Index


PAINTING A FENCE
Example of Systems Variability Analysis
Suppose you want to paint a fence (2 sides, 2 coats).
How much paint do you need?
Return
Next

# DETERMINISTIC ANALYSIS

## Find a Single Best Estimate

**POINT ESTIMATES:**

| | |
|---|---|
| Number of sides: | 2 |
| Number of coats: | 2 |
| Height of fence: | 1 m |
| Length of fence: | 25 m |
| Paint coverage: | 60 $m^2$/can |

**CALCULATION:**

Number of cans:

2 x 2 x 1m x 25 m/

(60 $m^2$/can)

= 1.7 can

**ANSWER:**

BUY 2 CANS OF PAINT

Previous

Next

# PROBABILISTIC ANALYSIS

## "Number of cans" is a Random Variable

**DISTRIBUTIONS:**

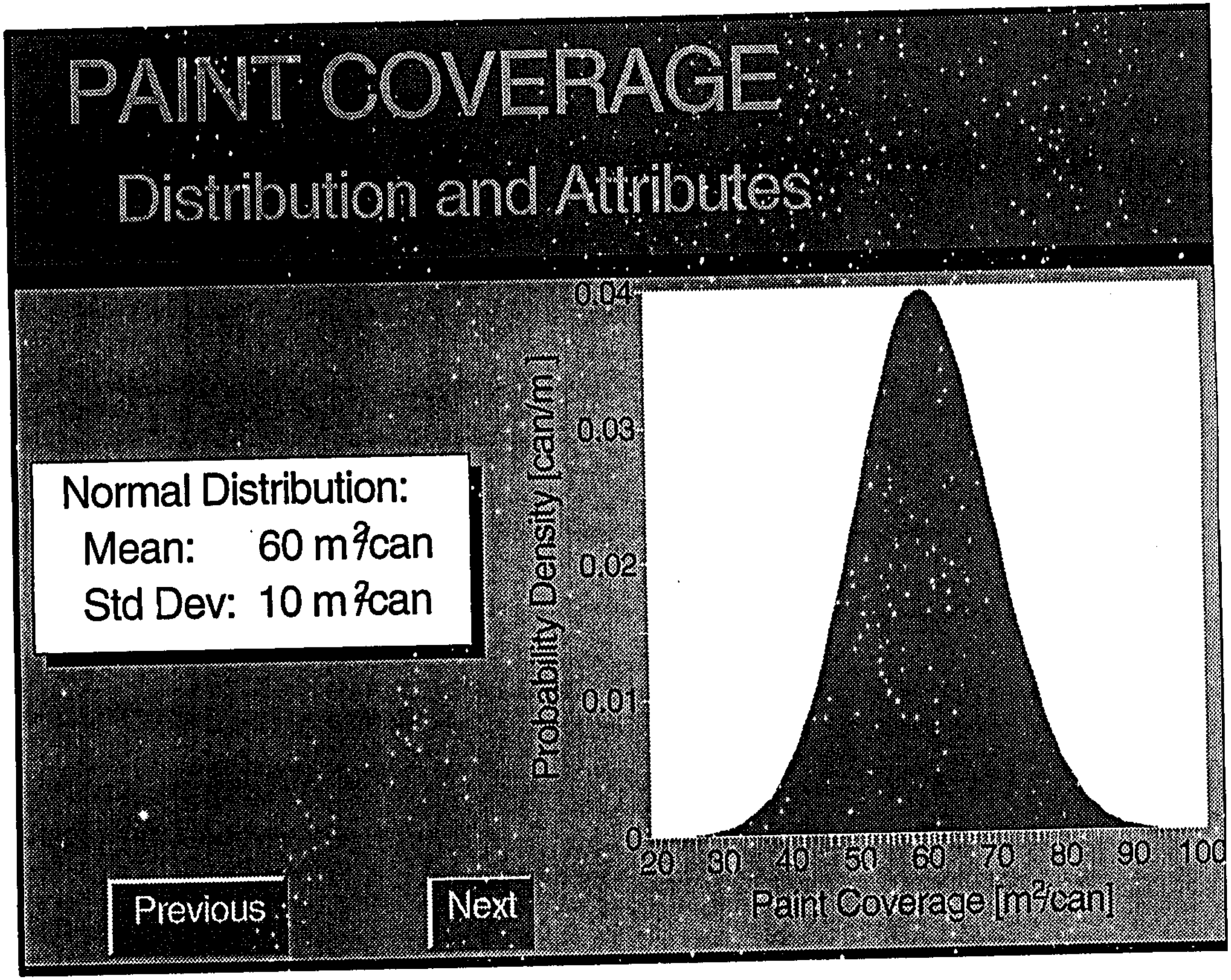
| | |
|---|---|
| Number of sides: | CONSTANT(2) |
| Number of coats: | CONSTANT(2) |
| Height of fence: | NORMAL(1 m, 0.1 m) |
| Length of fence: | NORMAL(25 m, 2 m) |
| Paint coverage: | NORMAL(60 $m^2$ /can, 10 $m^2$ /can) |

**CALCULATION:**

Number of cans = 2 x 2 x (fence height) x (fence length) / (paint coverage)

Previous

Next



PAINT COVERAGE
Distribution and Attributes
Normal Distribution:
Mean: 60 m²/can
Std Dev: 10 m²/can
Probability Density [can/m²]
0.04
0.03
0.02
0.01
0
20 30 40 50 60 70 80 90 100
Paint Coverage [m²/can]
Previous
Next

# Systems Variability Analysis

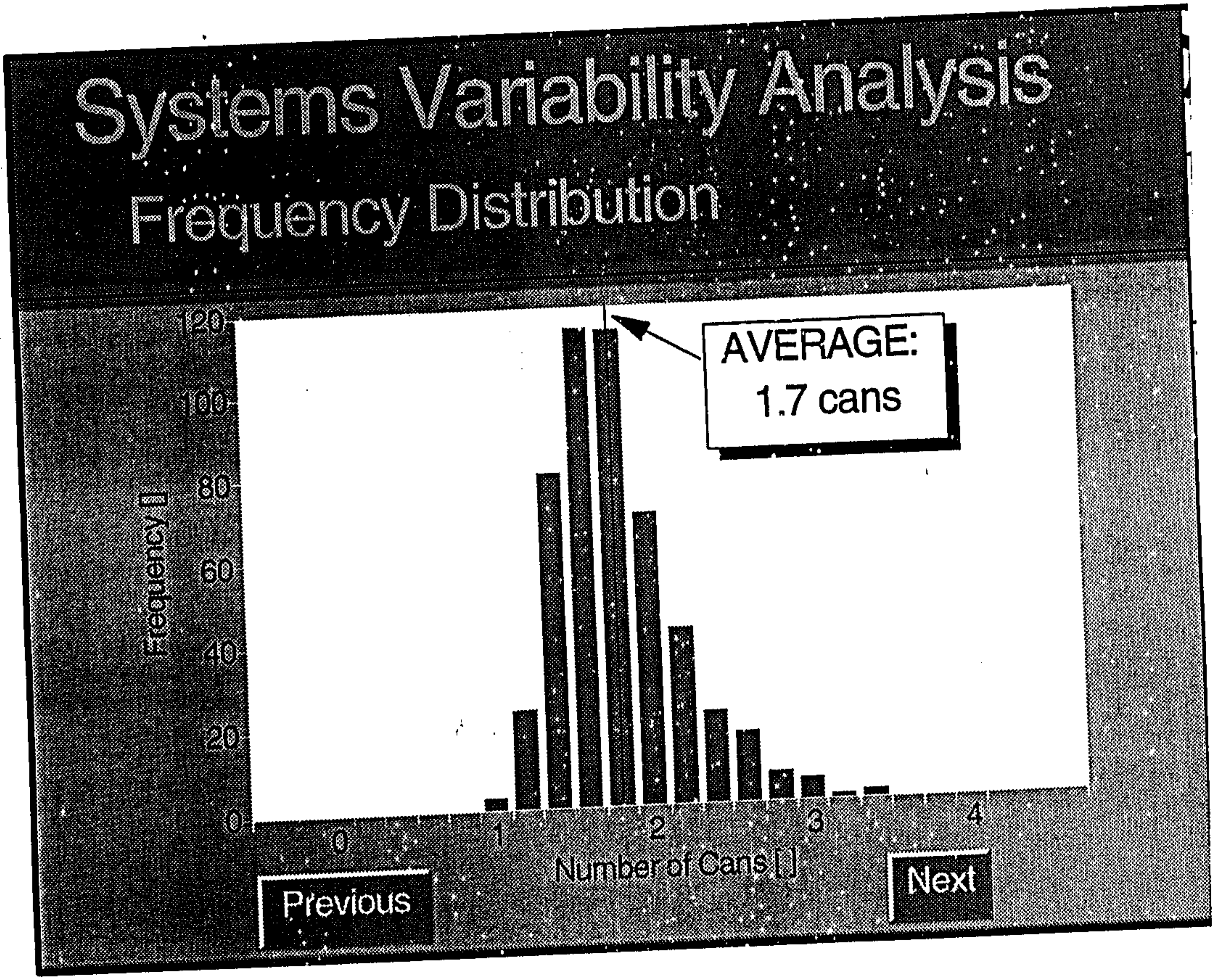
## Table of 500 Random Simulations

CALCULATION:

| Index | Height | Length | Coverage | Number of cans |
|---|---|---|---|---|
| (1) | 1.18 | 26.6 | 51.7 | 2.4 |
| (2) | 1.00 | 21.4 | 63.9 | 1.3 |
| (3) | 0.88 | 21.1 | 63.4 | 1.2 |
| (4) | 0.92 | 25.7 | 40.8 | 2.3 |
| (5) | 1.08 | 24.4 | 66.0 | 1.6 |
| . . . | | | | |
| (500) | 1.13 | 26.0 | 63.7 | 1.8 |

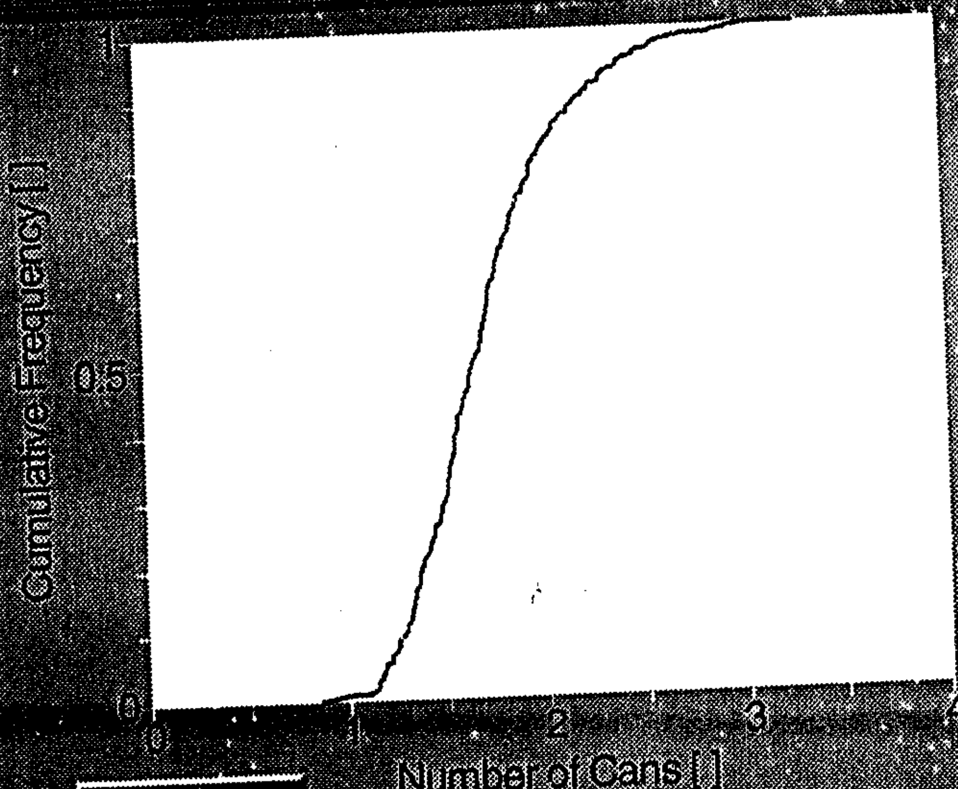
Previous

Next


Systems Variability Analysis
Frequency Distribution
AVERAGE:
1.7 cans
Frequency []
120
100
80
60
40
20
0
0
1
2
3
4
Number of Cans []
Previous
Next

# Systems Variability Analysis

## Cumulative Frequency Distribution




| Number of Cans | Fraction of Trials |
|---|---|
| 1 | 0.004 |
| 2 | 0.810 |
| 3 | 0.996 |
| 4 | 1.000 |

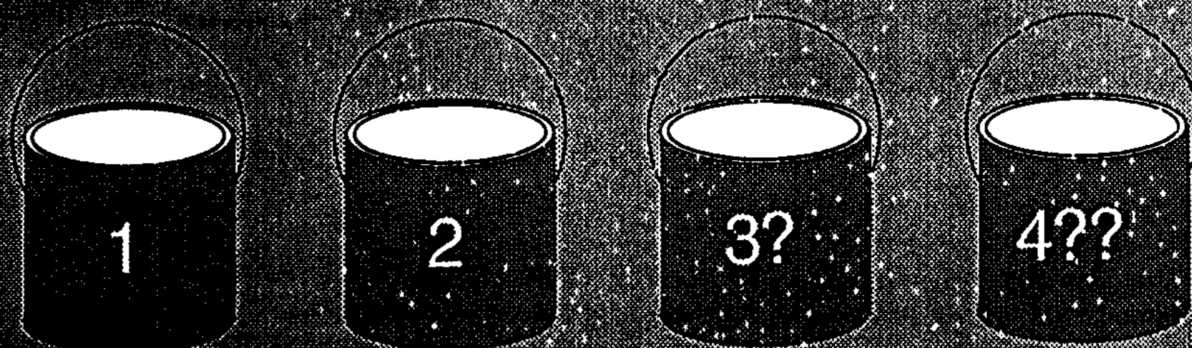
Previous

Next

# Systems Variability Analysis

## Decision-Making is Excluded

Systems Variability Analysis is a decision support tool, but it cannot make decisions for you.




Previous

Next

# Systems Variability Analysis

## Summary

- Develop a functional model
- Estimate probability distributions
- Repeatedly sample and simulate
- Estimate distribution of consequence

Previous

Return

# MODEL CHARACTERISTICS

- focussed on objectives
- defensible:

  verified and
  validated

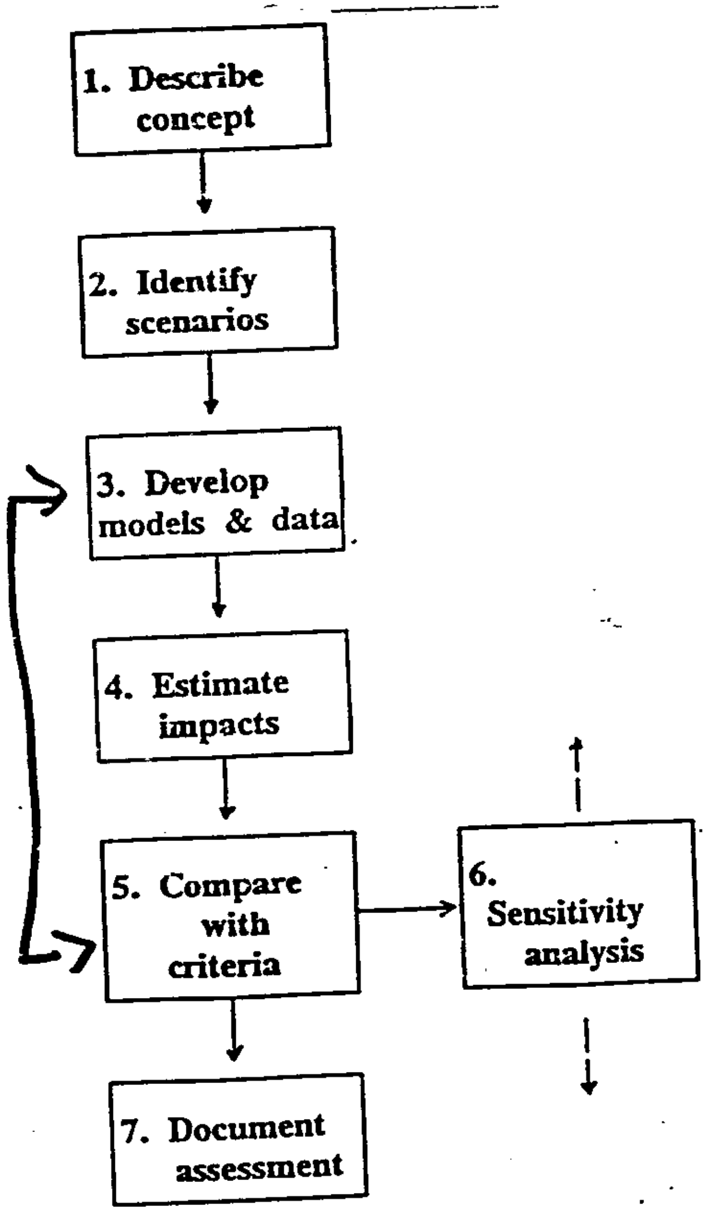
- robust and simple

(• account for uncertainty)

# Modelling and R&D

- must maintain a strong link for credibility
- the “experts” must support the modelling
- the “experts” must support the choice of data

# THE ASSESSMENT PROCESS



# 1. DESCRIBE CONCEPT

**Eg. Nuclear Waste Management**

- high-level/low-level
- geological/subseabed
- engineered barriers
- types of impact
- acceptance criteria

# 2. <u>IDENTIFY SCENARIOS</u>

- what could affect disposal performance?

- used to "simplify" the analyses

- two steps:

  - identification
  - description

- procedure based on the SNL/NRC "risk assessment methodology" with updates from an NEA working group

## 3. DEVELOP MODELS AND DATA

- emphasis is to bound impacts, not forecast future

- Requirements:
  - quantitative
  - capable of extrapolation
  - defensible
  - (- conservative)
  - (- simple)

# 4. <u>ESTIMATE IMPACTS</u>

- individual/population doses
- performance objectives
- chemical toxicity
- environmental effects/resource use

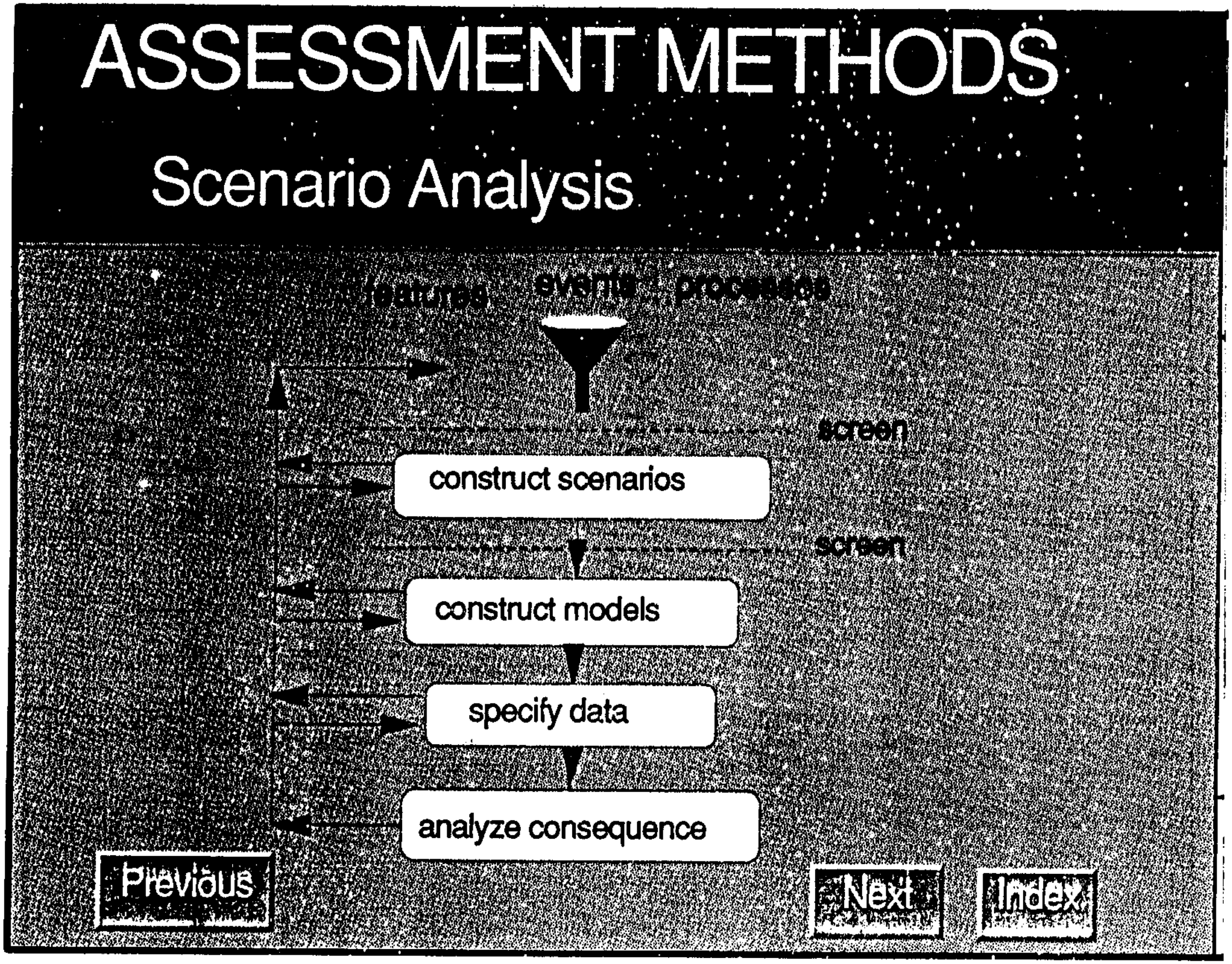
## 5. COMPARE WITH CRITERIA

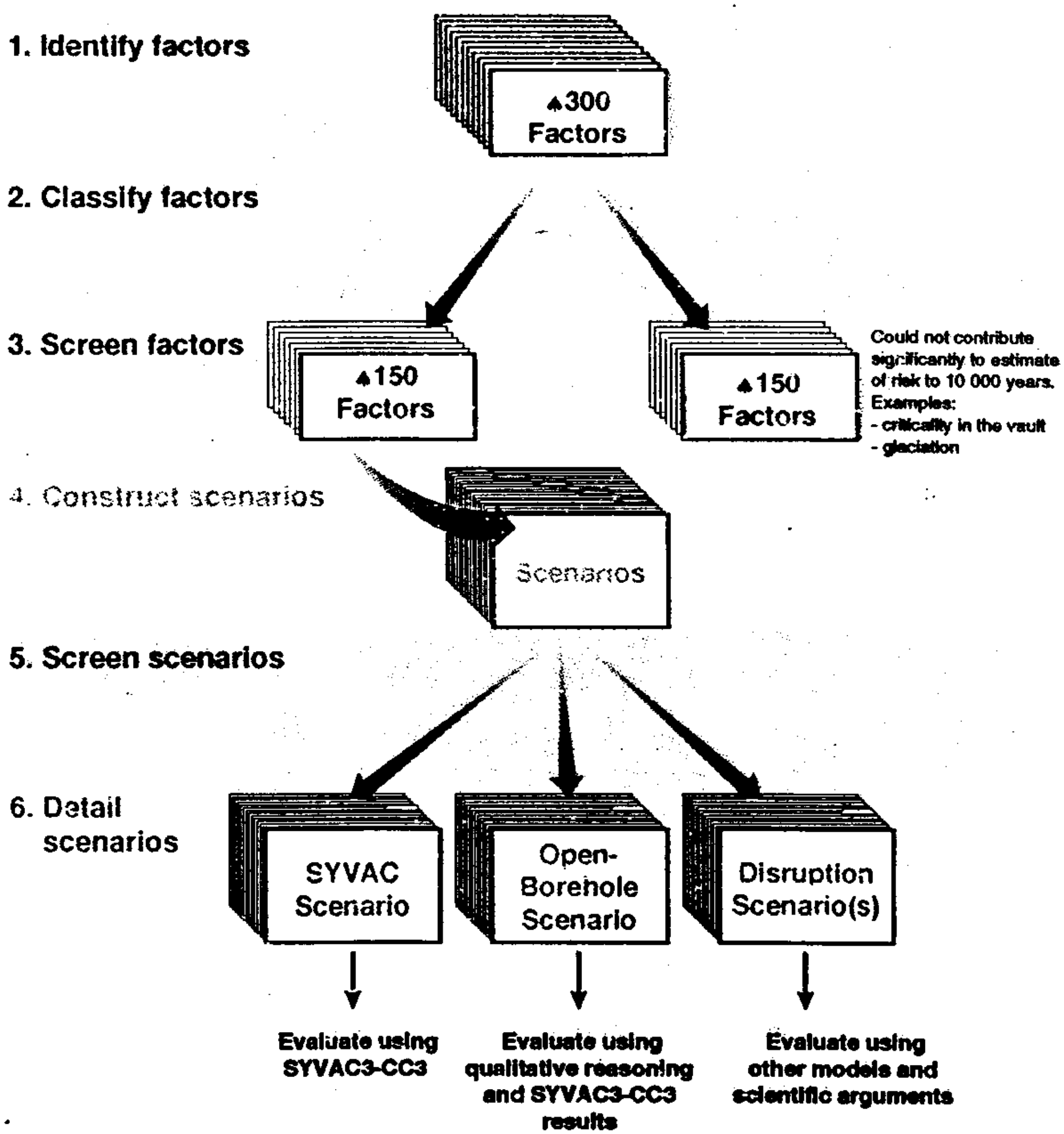
- acceptable/unacceptable/ conditionally acceptable?

- confidence?

(• cost effective?)

(• optimal?)

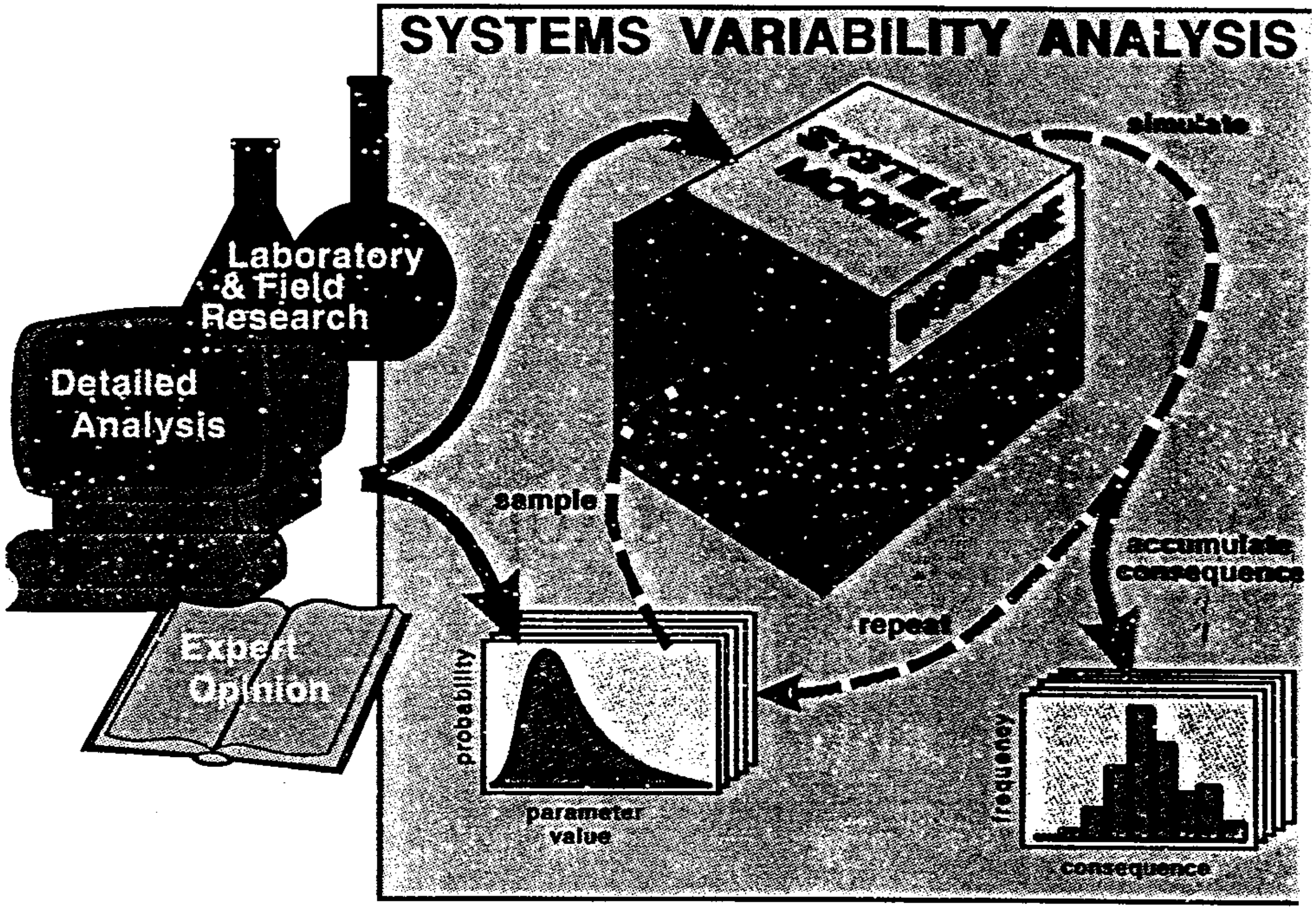

ASSESSMENT METHODS
Scenario Analysis
features
events
processes
screen
construct scenarios
screen
construct models
specify data
analyze consequence
Previous
Next
Index


1. Identify factors
♠300 Factors
2. Classify factors
3. Screen factors
♠150 Factors
♠150 Factors
Could not contribute significantly to estimate of risk to 10 000 years. Examples:
- criticality in the vault
- glaciation
4. Construct scenarios
Scenarios
5. Screen scenarios
6. Detail scenarios
SYVAC Scenario
Open-Borehole Scenario
Disruption Scenario(s)
Evaluate using SYVAC3-CC3
Evaluate using qualitative reasoning and SYVAC3-CC3 results
Evaluate using other models and scientific arguments

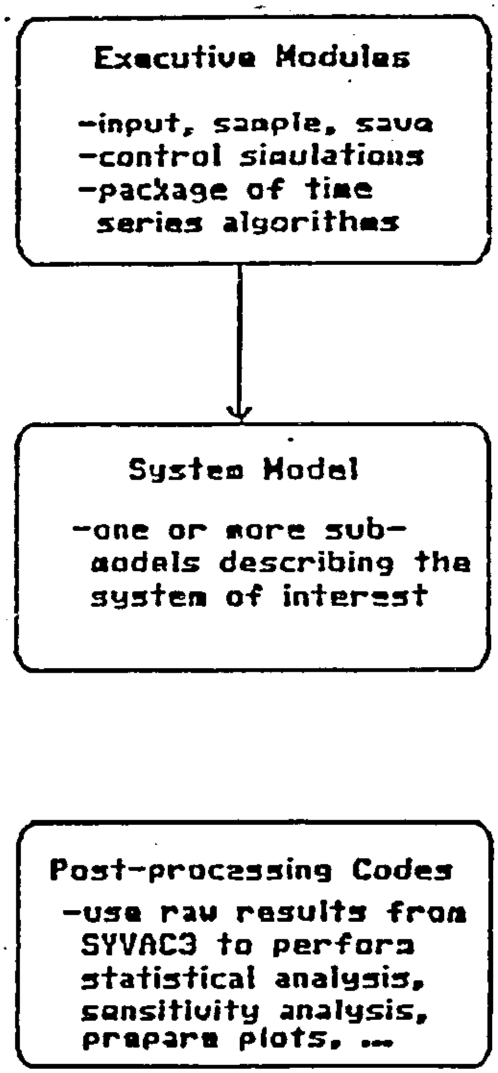
# SYVAC

## SYSTEMS VARIABILITY ANALYSIS CODE

## A PROBABILISTIC ASSESSMENT TOOL


SYSTEMS VARIABILITY ANALYSIS
Laboratory & Field Research
Detailed Analysis
Expert Opinion
SYSTEM MODEL
simulate
sample
accumulate consequence
repeat
probability
parameter value
frequency
consequence

# An Overview of the SYVAC3 Structure



# SYVAC3 Executive Code

- Structured FORTRAN 77 code
- 15000 to 20000 lines of code
- 177 modules
- developed in stages over 15 years

## SYVAC - SYstems Variability Analysis Code

| | |
|---|---|
| SYSTEMS ASSESSMENT | - integrated analysis of the performance of multicomponent systems |
| VARIABILITY & UNCERTAINTY | - parameters given as probability density functions |
| MODULAR | - submodels describing engineered/natural systems easily coupled to executive |
| PROBABILISTIC METHODOLOGY | - Monte Carlo approach; risk criteria given as probability vs consequences |
| LONG TIME FRAMES | - variable time steps up to $10^7$ years and beyond |
| RADIOLOGICAL EFFECTS | - n-member decay chains; radiological dose to an individual in a reference group |
| NONRADIOLOGICAL EFFECTS | - concentrations and fluxes of contaminants in geosphere and biosphere compartments |
| ADVANCED SOFTWARE ENGINEERING | - structured programming, software standards, quality control procedures, testing and validation |
| MULTIDISCIPLINARY DEVELOPMENT | - $XM investment; 1980-1996; strong linkage to field and laboratory programs |

# Functions of SYVAC3

(executive/driver for systems model execution)

- control of model execution
- control of input/output
- control/assignment of parameter values
- simple connection to embedded systems model
- provides modelling tools

# Control of Model Execution

- direction given in first few lines of input file
- set of simulations/single simulation
- probabilistic/deterministic
- copes with bad data sets

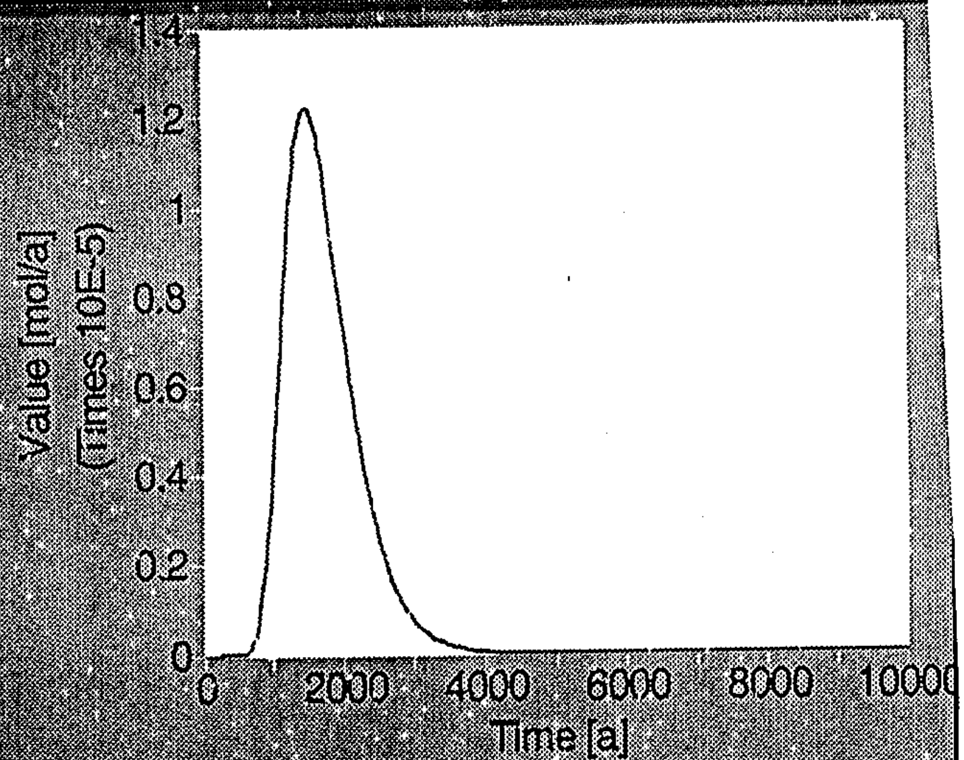
# Control of Input/Output

- flexible file reading features
- user friendly/readable input files
- optional output files

# TIME SERIES ROUTINES

## Introduction

A SYVAC3 time series is a curve representing a function of time from 0 to a time limit.



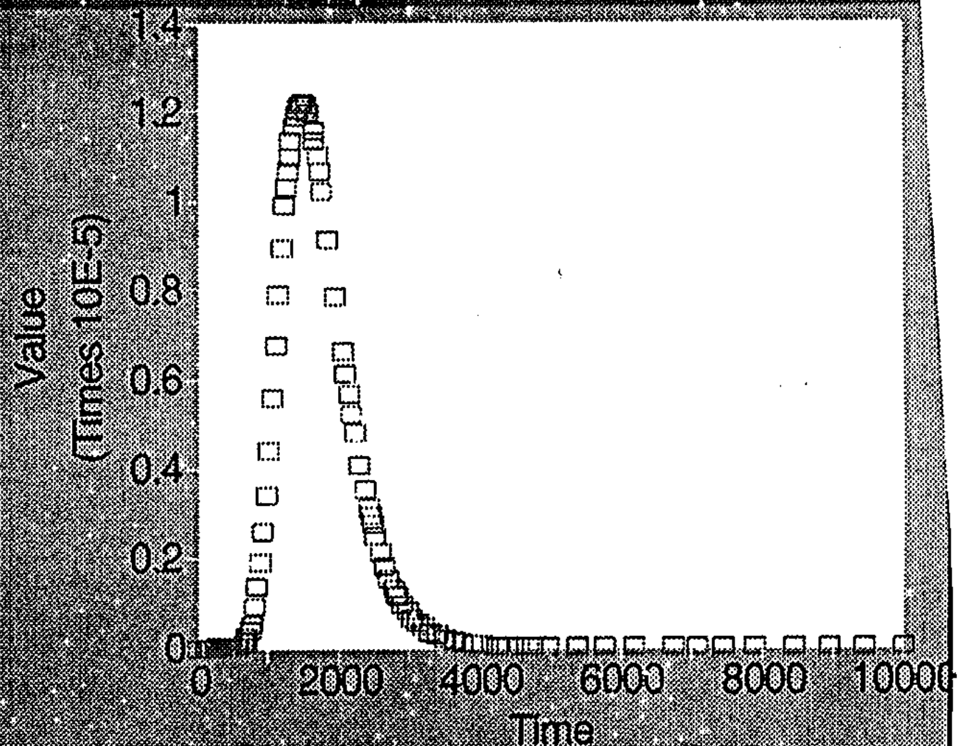

Return

Next

# TIME SERIES ROUTINES

## Approximation From Discrete Points

A SYVAC3 time series is based on a set of unevenly-spaced discrete points from the true curve.



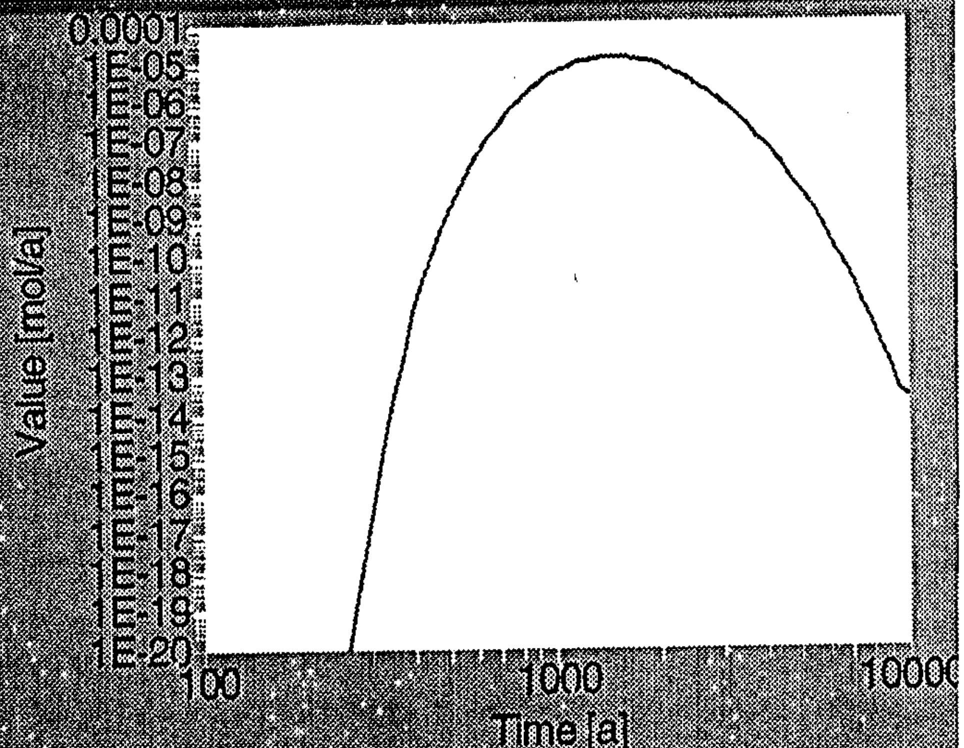

Previous

Next

# TIME SERIES ROUTINES

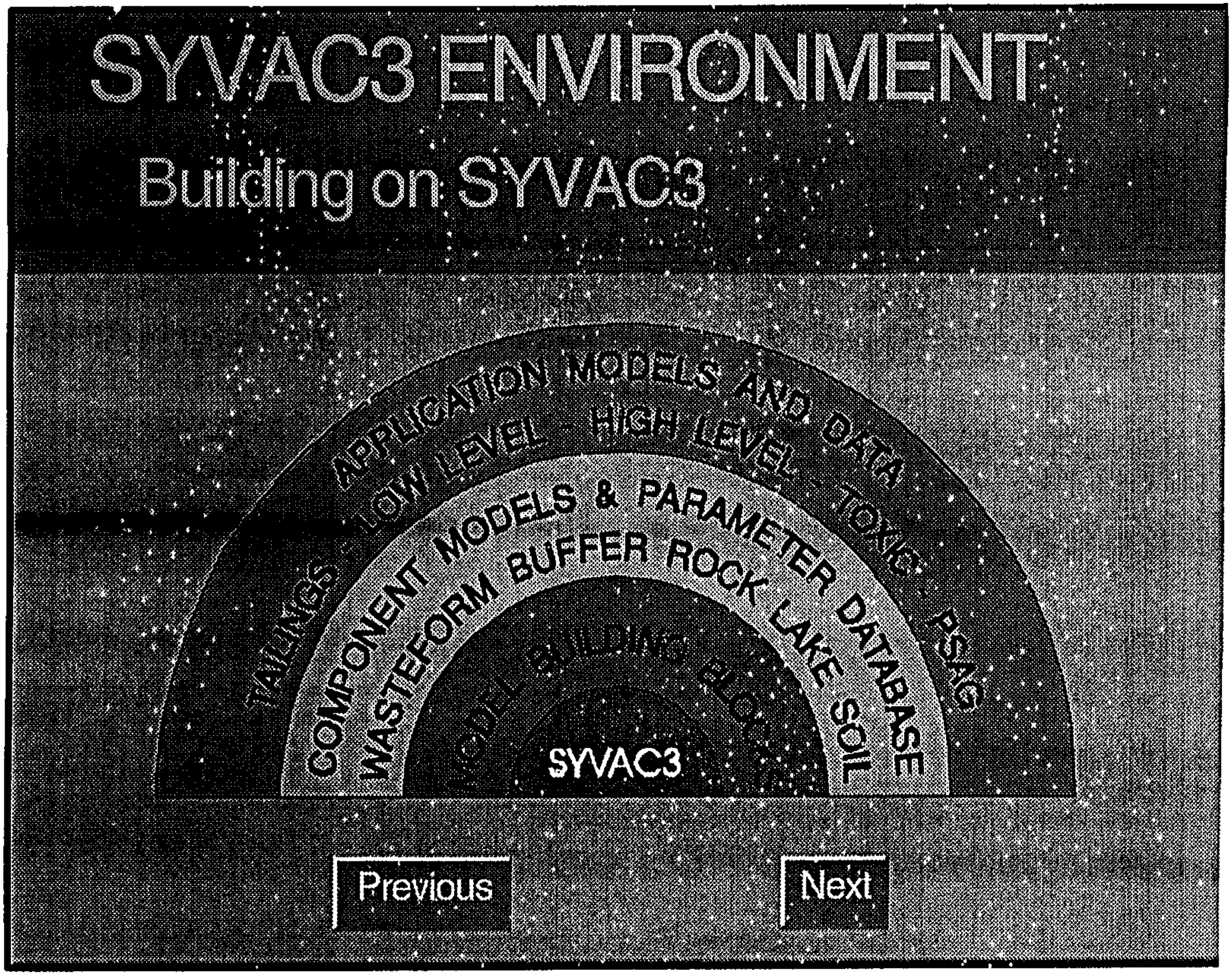
## Should Look Smooth on a Log Scale

This time series is the same as in the previous screen, but it is shown on a log-log scale. It still looks smooth.




Previous

Next


SYVAC3 ENVIRONMENT
Building on SYVAC3
APPLICATION MODELS AND DATA
TAILINGS LOW LEVEL HIGH LEVEL TOXIC PSAG
COMPONENT MODELS & PARAMETER DATABASE
WASTEFORM BUFFER ROCK LAKE SOIL
MODEL BUILDING BLOC
SYVAC3
Previous
Next

## SYSTEMS MODELING

- a dynamic process
- requires creative thinking
- gives a flexible product amenable to further remolding
- provides simple truths and elegant revelations
- allows a situation to be viewed from many perspectives
- will ask you questions, ones you haven't thought of before
- have a way of letting you know when you have made clumsy and useless choices