IAEA Regional Workshop
„Safety Considerations of Disposal of Disused Sealed Sources in Near Surface Facilities“

Approaches of Selecting Options for Upgrading of Safety of Near Surface Facilities

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Overview

- **Goals in intervention situations**
- **General approach to optimisation**
- **Methods:**
  - Cost-benefit analysis
  - Multi-attribute utility analysis
- **Consideration of unplanned events**
- **Uncertainties**
- **Examples**
- **Conclusions**

Background

starting point

intervention situation
(risks exist already)

goals

improvement of safety

cost optimisation

approach

consideration of real risks

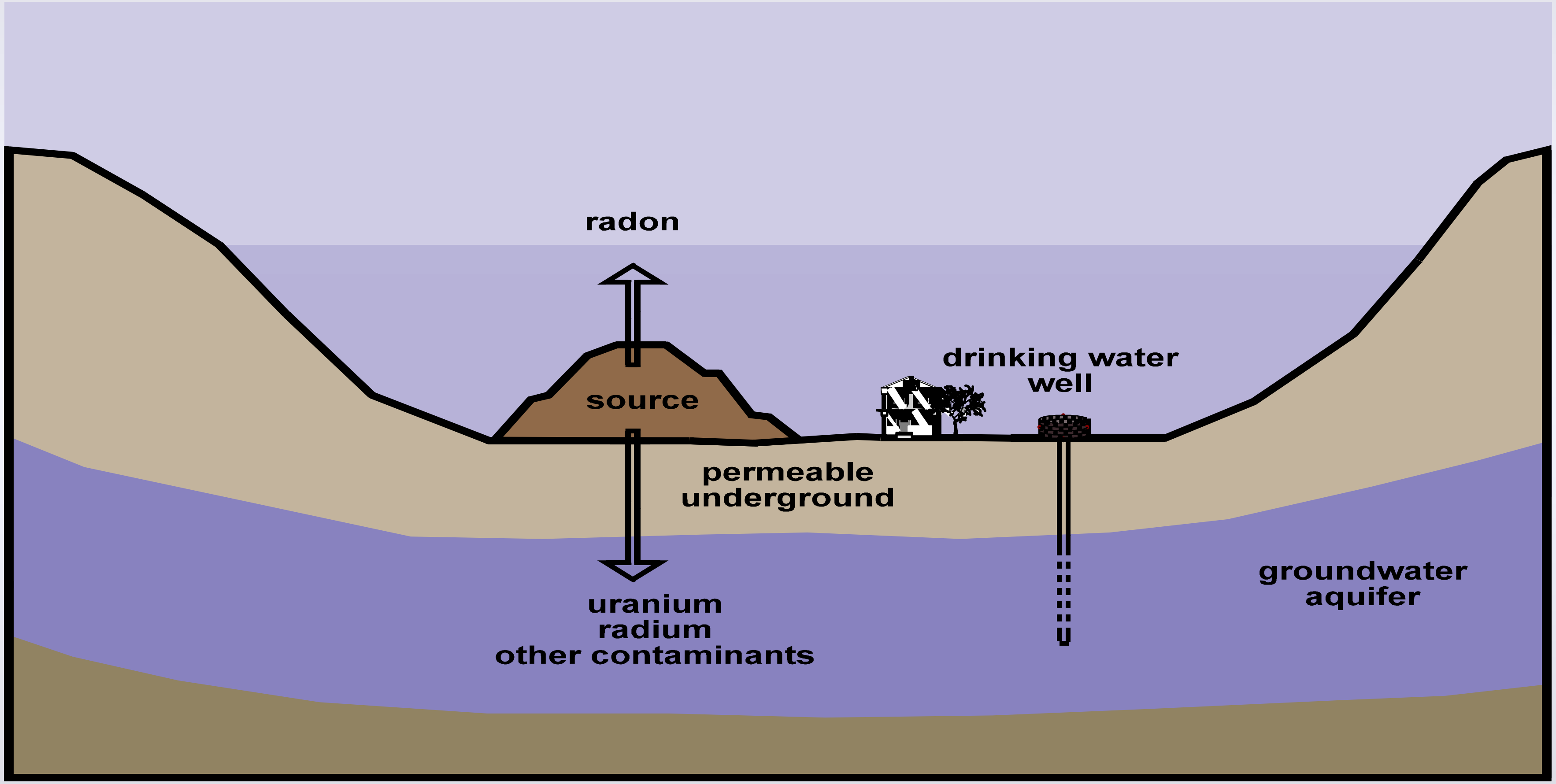
long term approaches

optimisation

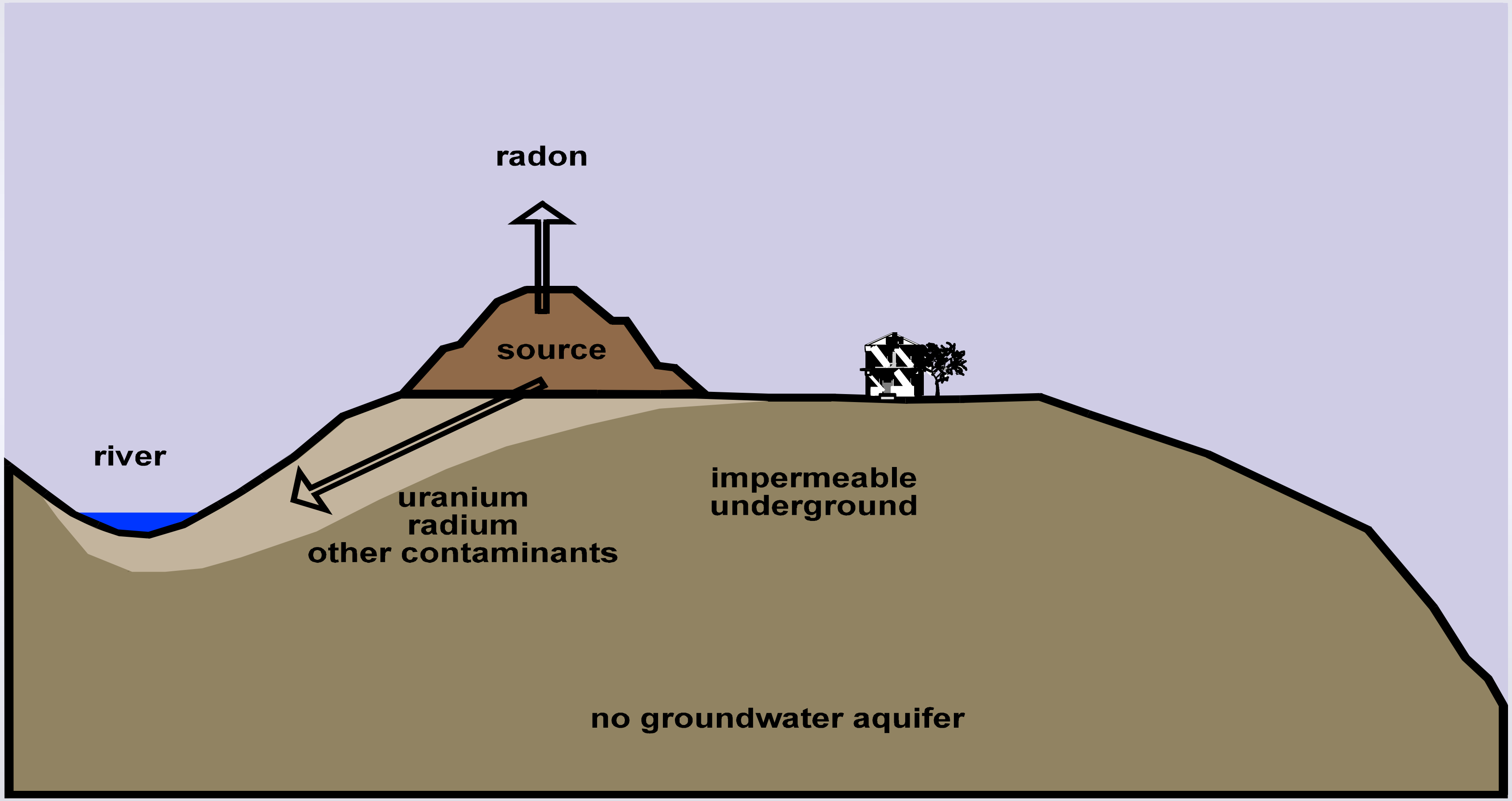
Assessment of remediation options

- **Minimum requirements on remediation options:**
  - reduction of risks according to regulatory minimum standards according to
    - radiation protection regulations
    - water protection regulations
    - ...
- **Selection of remediation options which are in compliance with these requirements**
- **Justification of remedial measures**
- **Optimisation of remedial measures (balancing benefits and detriments of options)**

Critical Exposure Conditions



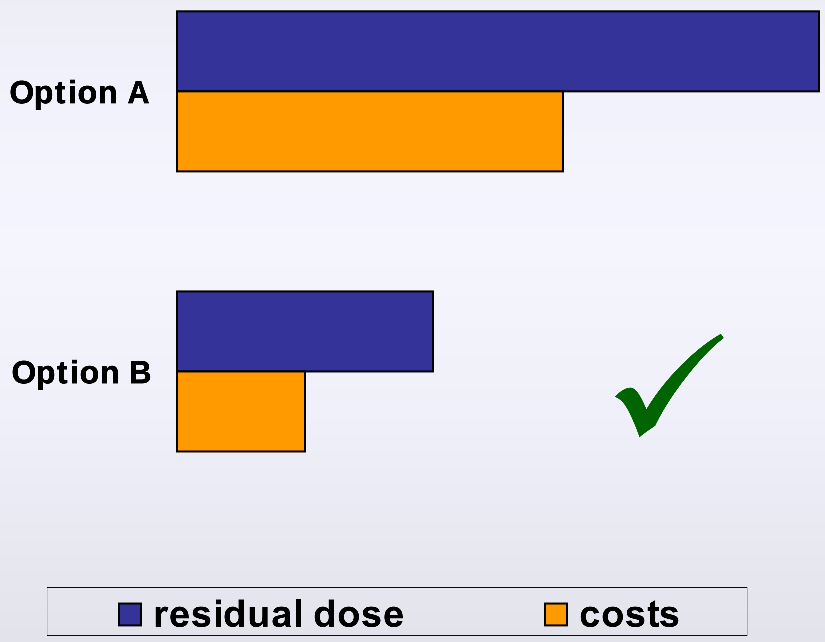
Less Critical Exposure Conditions

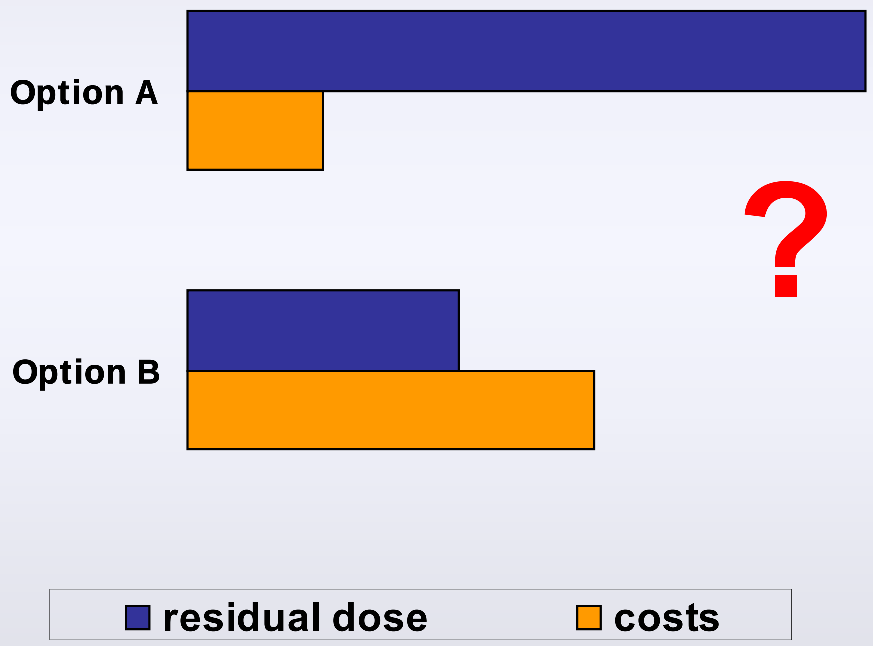


Principle Aspects of Optimisation

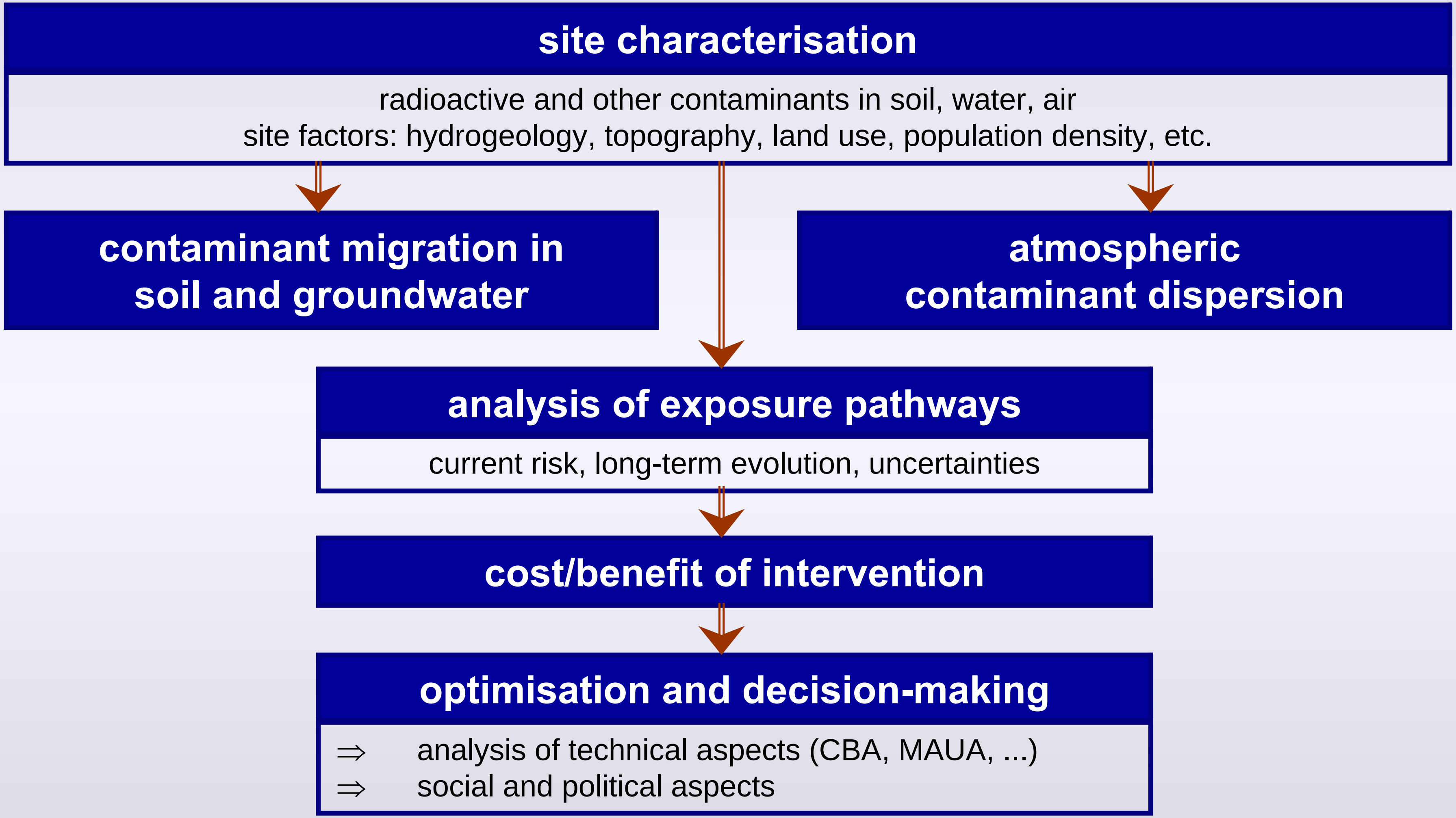
Carrying out optimisation considerations

simple situation	difficult situation (normal case)

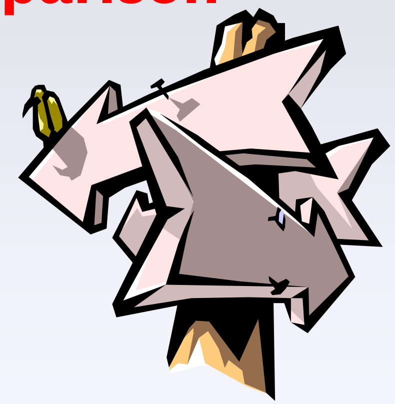




Overview: Decision-Making



Optimisation – General Aspects



- **Comparison of options through qualitative comparison**
  - difficult for many factors of influence
  - subjective
  - difficult to communicate and to defend
- **Alternative: quantitative optimisation**
  - risks (mSv/a) and costs: different units
  - required: common measure for the total detriment
  - individual dose does not represent radiological detriment
    - ➢ number of exposed persons relevant
    - ➢ 1000 exposed persons with 0,5 mSv/a result in higher total risk as 10 exposed persons with 1 mSv/a
  - methodology for carrying out the optimisation required

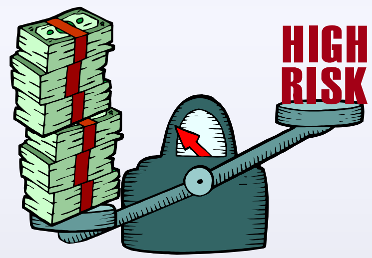
Principle of Cost-Benefit Analysis (CBA)

- **Quantitative optimisation: integrated measure of detriment D**

collective radiological risks
financial expenditures
non-radiological risks
possibly ecological risks
other factors

} **D**

- **Common measure for detriment: monetary equivalent**



Goal: Basis for decision-making

Quantification of Risks

- **Radiological risks:**
  - maximum individual dose
  - collective dose
- **Risks through chemically cancerogenic substances:**
  - individual and collective risks
  - risk coefficients (i.e. US EPA)
- **Common unit:**
  loss of life expectancy (LLE)

- **Integration of radiological and other risks:**

1 Sv ≈ 1 year LLE

Application of CBA

Monetary equivalent of risk reduction (α)
justified expenditures for a risk reduction (years LLE) considering available resources and other requirements of society

range for α:	50.000 - 150.000 Ђ/a LLE
mean value:	100.000 Ђ/a LLE

total detriment =
financial expenditures + α · collective risk

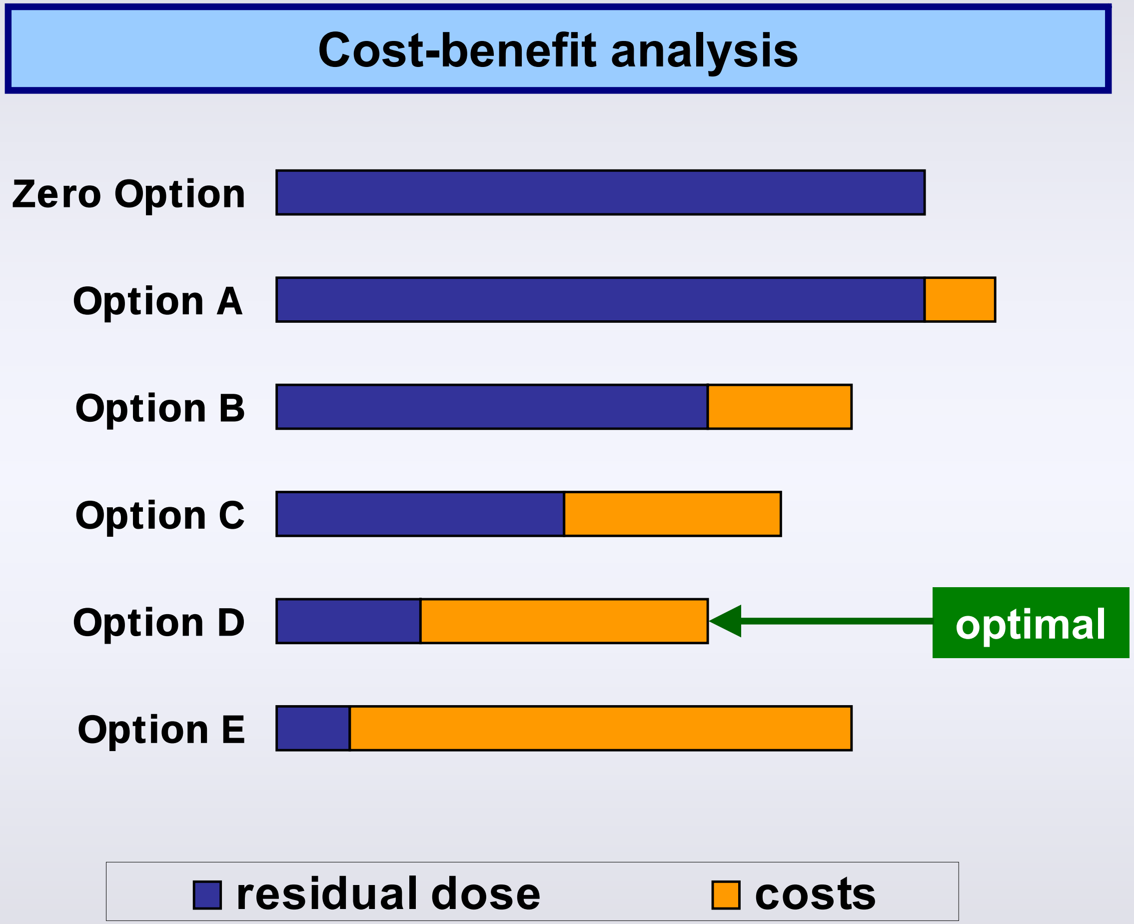
Financial Expenditures

- **Cost components**:
  - immediate costs for intervention
  - long-term costs for
    - maintenance
    - surveillance
    - restrictions on land use
- **Long-term discount factors (to calculate net present value)**

current value: 2 – 5 % p.a. (mean 3,5 % p.a.)

justified value between generations: 1-2 % p.a.

Example: Justification and Optimisation



Option	Justification		max. dose (mSv/a)
Zero Option			2,5
Option A	justif.	justif.	2,0
Option B	justif.	justif.	1,5
Option C	justif.	justif.	0,8
Option D	justif.	justif.	0,8
Option E	justif.	justif.	0,8

Multi-Attribute Utility Analysis

- **Allows inclusion of qualitative factors**
- **Translation of qualitative aspects (e.g. jobs, land use) into scales of preference**
- **Definition of relative weights between various qualitative and quantitative factors**
- **Advantages:**
  - stakeholders can be involved in defining utility functions
  - defensibility of decision-making
  - broad basis for consensus for decision-making achievable

Assessment of Remediation Options

- **Modelling of exposures – contaminant release and migration (atmospheric, groundwater) and potential for intrusion:**
  - development and calibration of site specific models
  - identification of relevant exposure mechanisms
- **Assessment of possibilities for risk reduction through remedial action**
- **Assessment of possibilities of risk reduction by intervention**
- **Assessment of uncertainties**
- **Scenarios:**
  - reference scenarios
  - alternative scenarios

Unplanned Events (Alternative Scenarios)

- **Taking account of possible unplanned events, such as**
  - erosion of covers
  - failure of structures
  - non-observance of land-use restrictions (intrusion)
- **Consideration of chains of events, such as:**

> **climate change**
> **➔ damage of vegetation on cover**
> **➔ erosion of cover**
> **➔ increased leach rate of contaminants**

- **Probability & consequences depend on institutional control**
- **Analysis of events based on probability estimates and consequence models**

Uncertainties

- **Sources of uncertainties:**
  - deficiencies of site characterization
  - model restrictions
  - statistical nature of input parameters (e.g. distribution of kd's or kf's, meteorological parameters, earthquake probabilities)
  - future developments
- **Deterministic sensitivity analysis (for simple systems)**
- **Monte-Carlo simulation techniques, advantages**
  - takes account of uncertainties consistently
  - works for complex systems as well
  - easy interpretation of results
  - consistent consideration of low probability events

Examples

Uranium mining example

Comparison of options for interim storage facility

Application to Tailings Impoundment

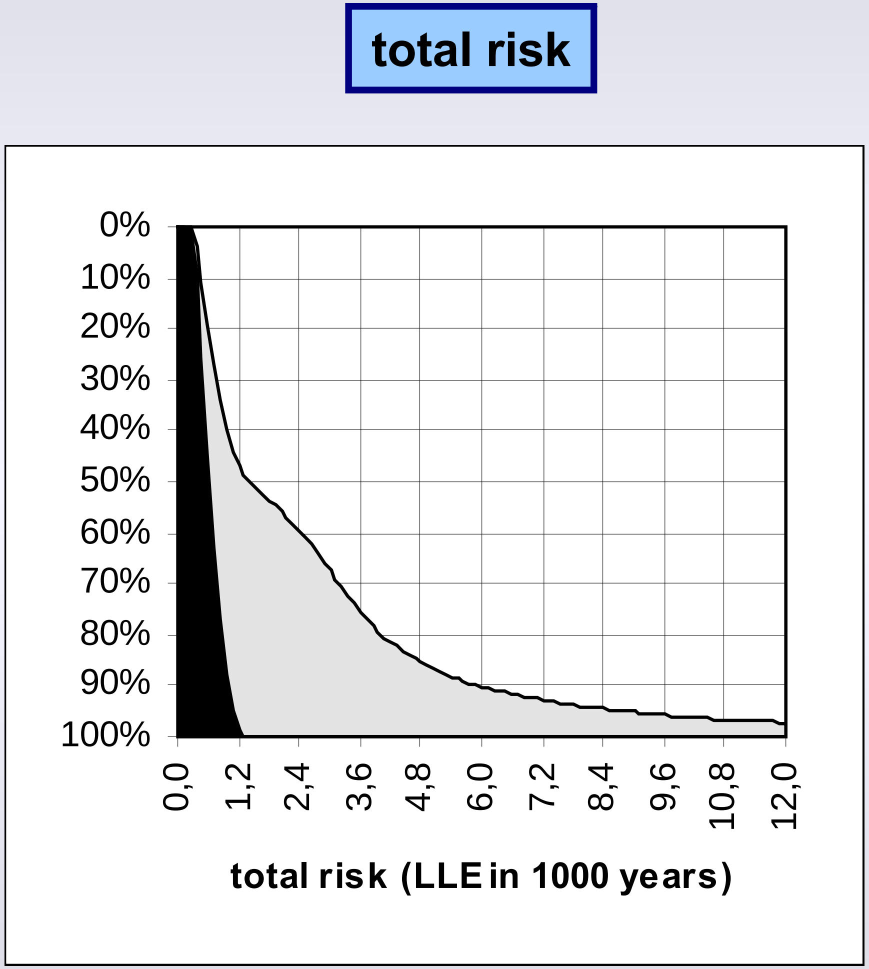
total area		220 ha
volume	tailings water portion	45 million m^3 24 million m^3
tailings	uranium radium-226 arsenic	49 - 270 ppm 3.0 - 10.2 Bq/g 50 - 600 ppm
water	free water	pore water
uranium radium-226 arsenic	5 - 7 mg/l 1.2 Bq/l 100 mg/l	2 - 30 mg/l 0.5 - 2 Bq/l < 6 mg/l

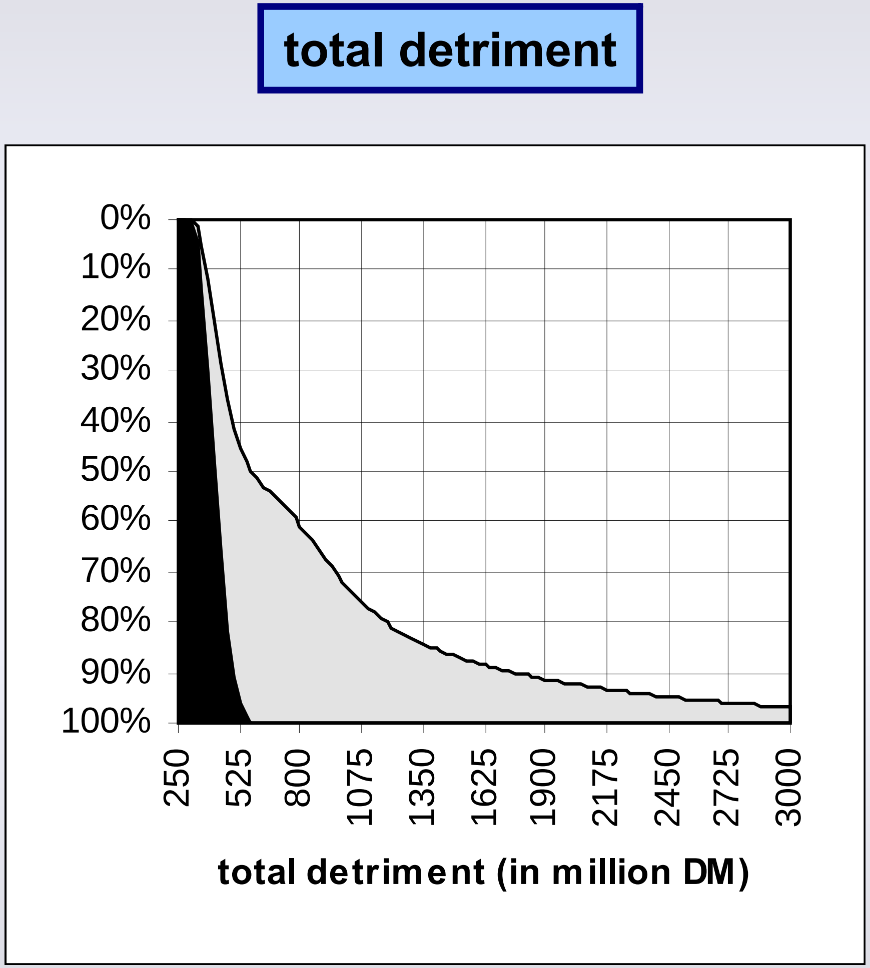
Reclamation Options Considered

- **Primary reclamation options considered**
  - wet reclamation with low water table - small lake (Option 1)
  - wet reclamation with high water table - large lake (Option 2)
  - dry reclamation with simple cover (Option 3)
  - dry reclamation with complex cover (Option 4)
- **Sub-options**
- **Targets of probabilistic simulation for each option:**
  - total risk (radiological and conventional)
  - financial expenditures
  - target quantity of cost-benefit analysis:

$$\text{total detriment} = \text{financial expenditures} + \alpha \times \text{total risk}$$

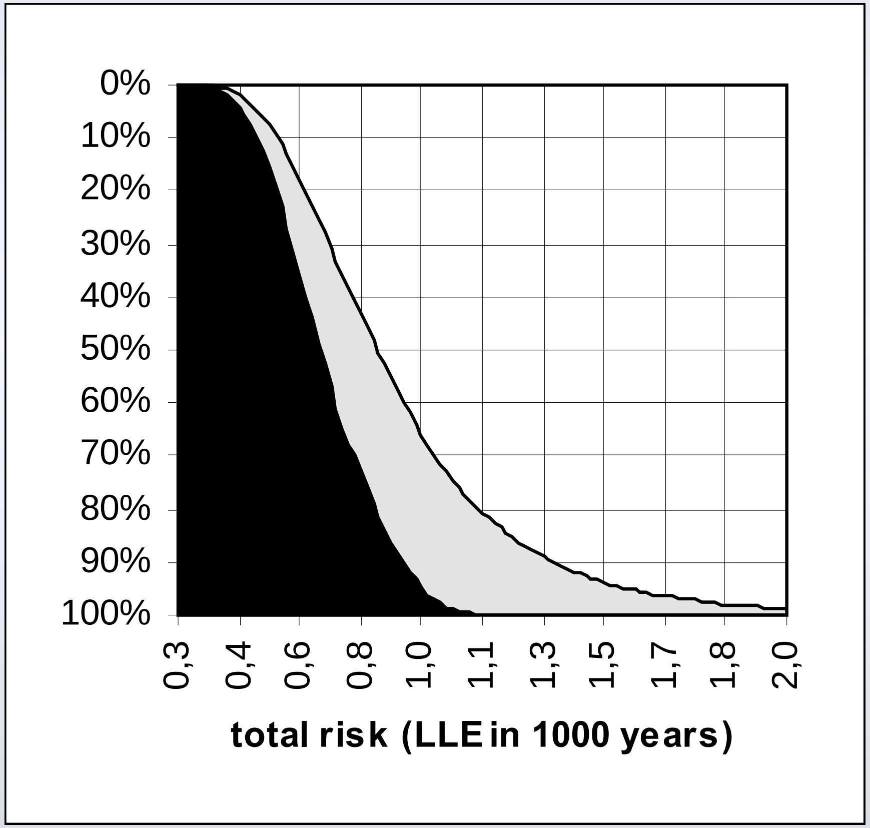
Large Lake Option 2



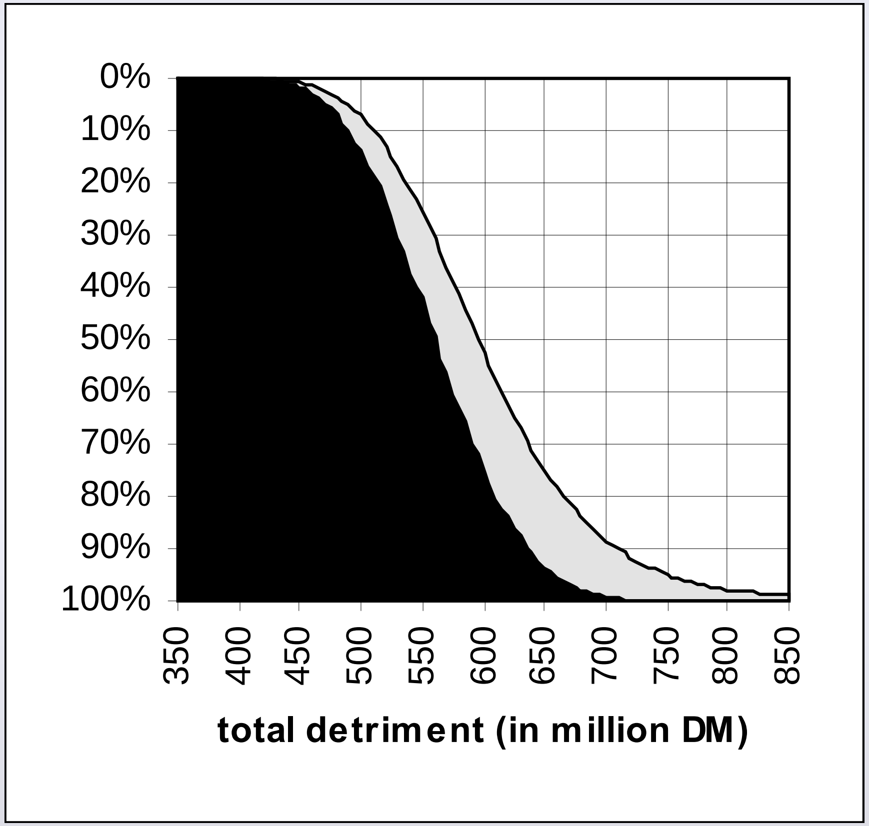


Complex Cover Option 4

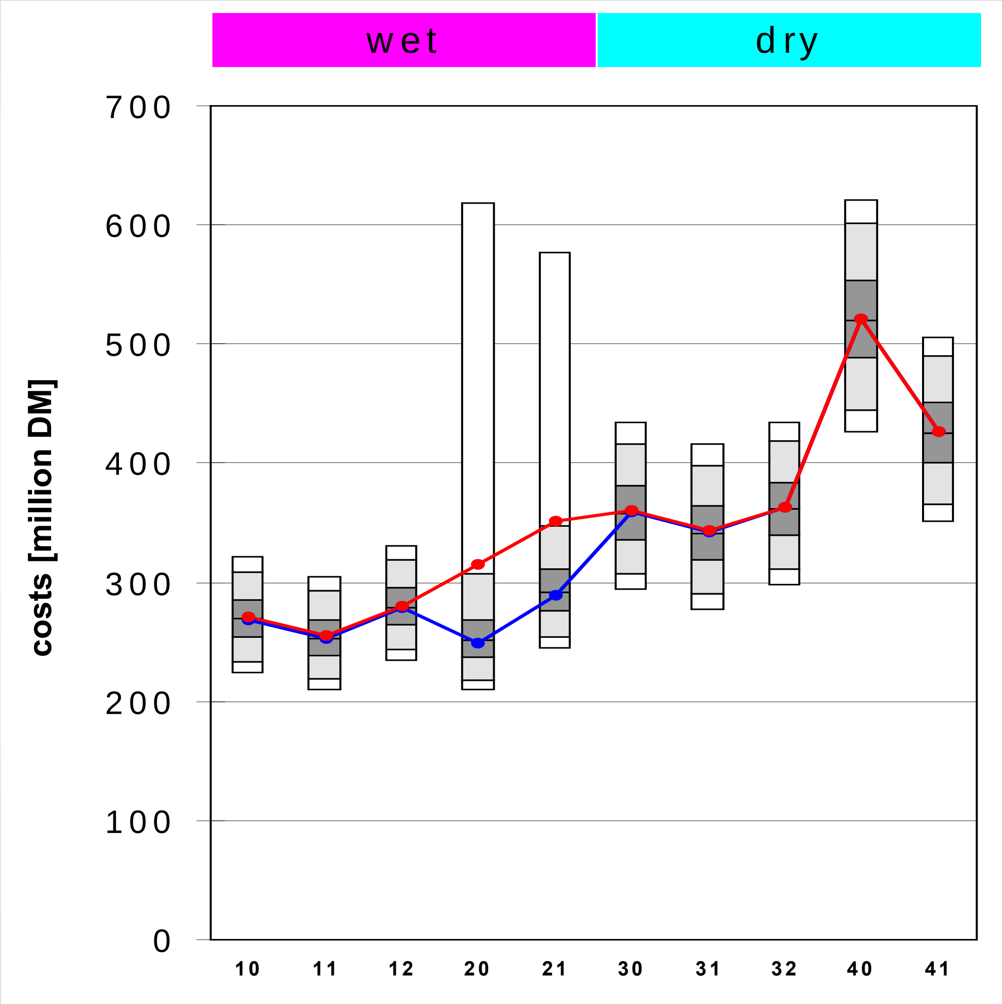
total risk



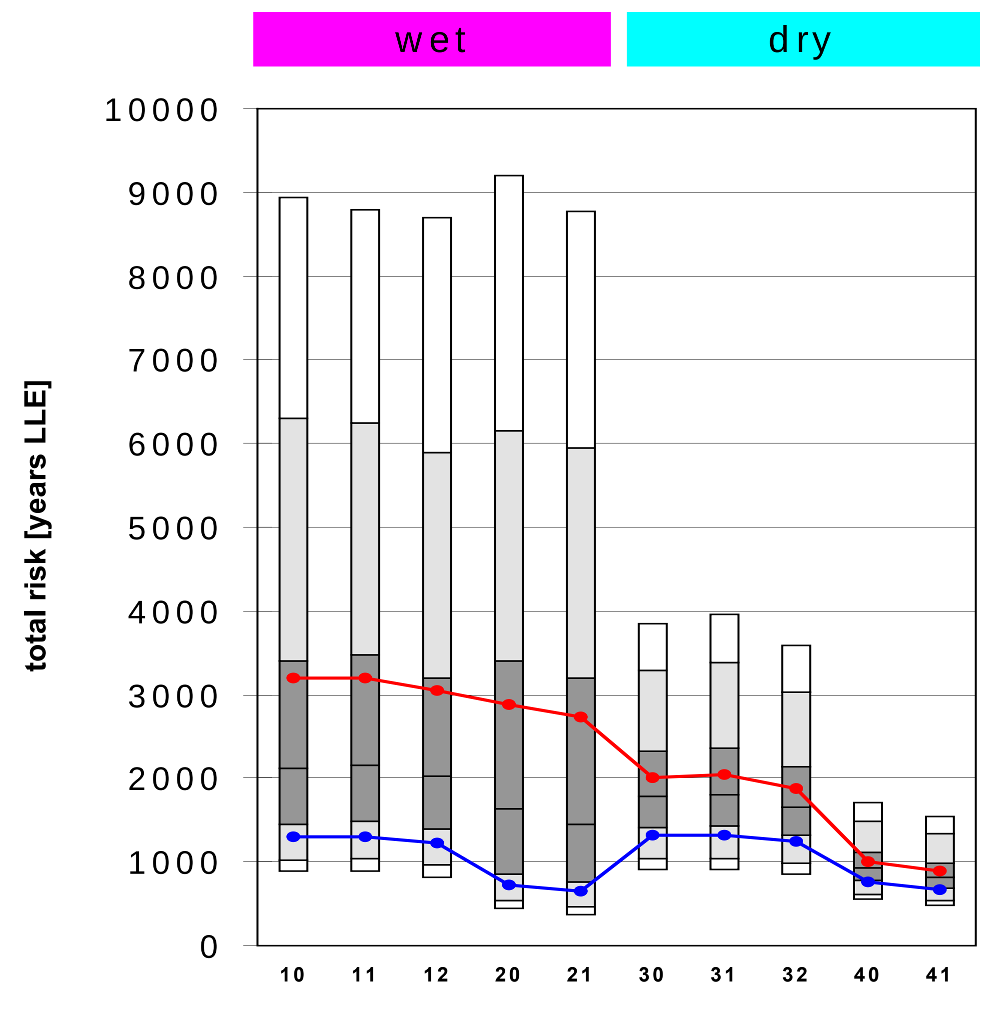
total detriment



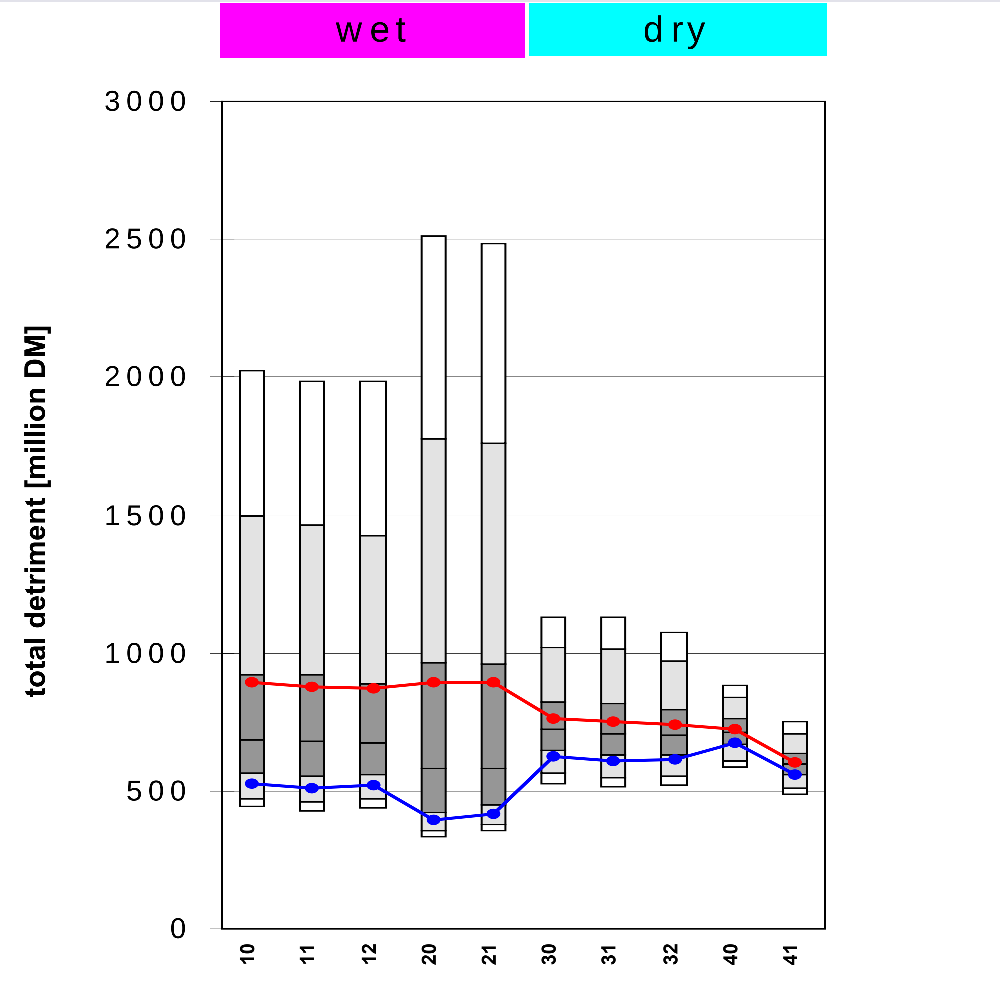
Financial Expenditure (incl. failure scenarios)



Total Risk (incl. failure scenarios)



Total Detriment (incl. failure scenarios)



Conclusions from Example

- **Quantitative optimisation** necessary in order to arrive at conclusion (higher financial expenditures yield lower risks)
- Only inclusion of **failure scenarios** reveals that **passive safety** of wet option is not satisfactory
- **Probabilistic simulation** allows for keeping track of uncertainties and assessing their consequences within the decision-making process
- **Optimisation analysis** can be refined in the course of further reclamation planning to allow for questions on detailed design to be addressed

Pragmatic (non-quantitative) assessment cannot reveal how safe is safe enough

Interim Storage Facility for Radwaste

Options for waste storage:

- Construction of new Building
- Waste storage in existing building after refurbishment and extension
- Waste storage in ISO containers on concrete plateau with movable cover
- Waste storage in ISO containers on concrete plateau without cover
- Waste storage as concrete blocks on concrete plateau with movable cover
- Waste storage as concrete blocks on concrete plateau without cover

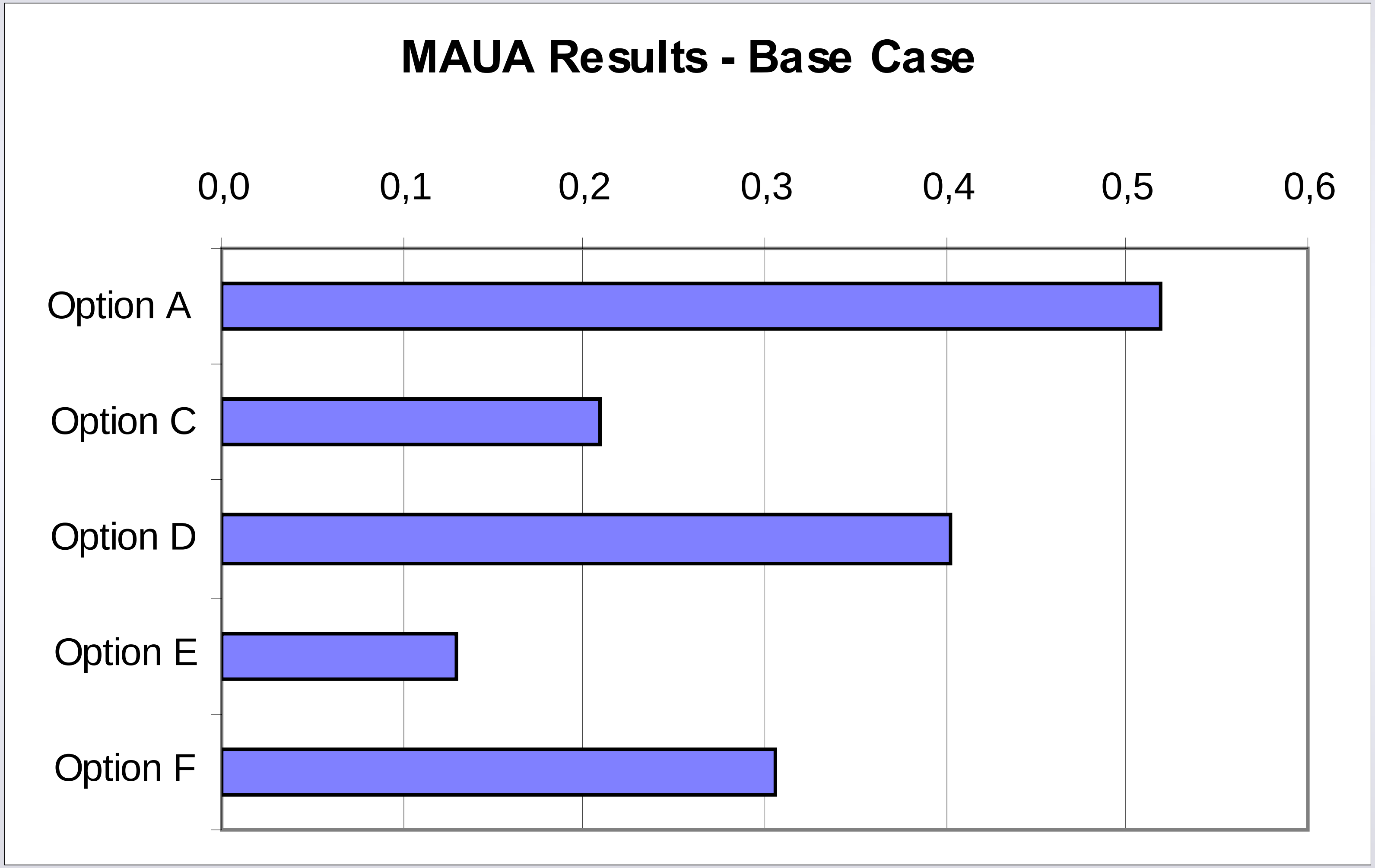
Factors Considered

Factor	Costs	Risk	qual.
Costs for implementation, maintenance and decommissioning			
- direct costs	x		
- ongoing costs	x		
- extra surveillance / maint.	x		
- decommissioning	x		
doses and risks reference scenario		x	
unplanned events (alternative scenarios)			
- fires	x	x	
- explosions	x	x	
- mechanical impacts	x	x	
- seismicity	x	x	
- acidic rain	x	x	
other factors			
- stability in time (extension of storage period)			x
- behaviour with respect to unexpected wastes arising			x
- time required for implementation			x

Methodology

- Estimate of cost components
- Discounting of long-term costs
- Estimate of risks
- Assessment of qualitative factors
- Definition of weighting factors
- Application of multi-attribute utility analysis
- Deterministic sensitivity analysis for important parameters

Results

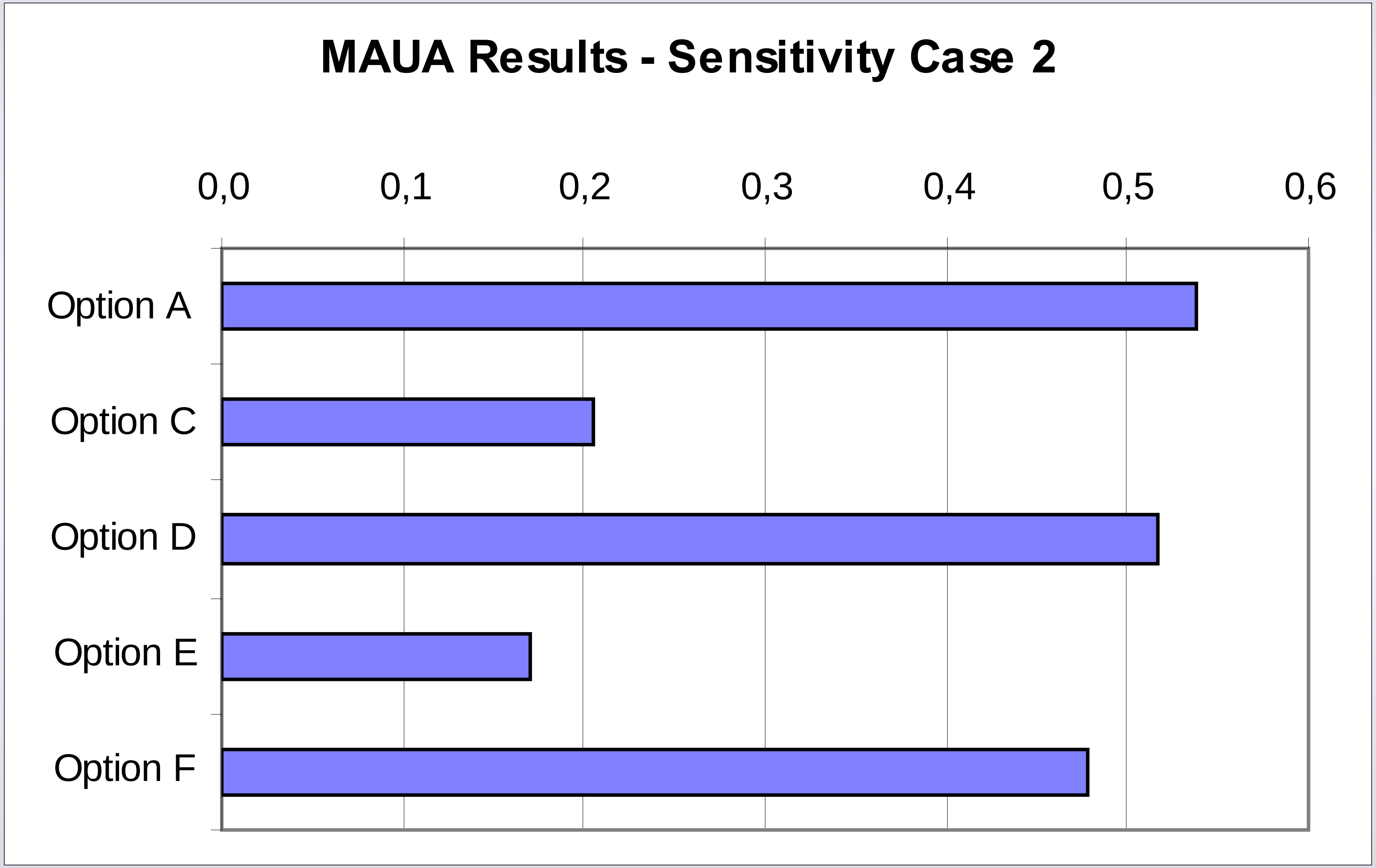


MAUA Results - Base Case
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Option A
Option C
Option D
Option E
Option F

Sensitivity Analysis

Sensitivity Case	Parameters Changed
1	Increase of relative weight of implementation, maintenance and decommissioning costs by a factor of 3
2	Decrease of relative weight of implementation, maintenance and decommissioning costs by a factor of 3
3	Increase of operational period to 50 years
4	Increase of real interest rate (discount factor) to 5 %
5	Decrease of real interest rate (discount factor) to 1 %

Results Sensitivity Case 2



Conclusion from Example

- **Sound basis for decision-making by identifying and assessing all factors of relevance**
- **Qualitative factors can be consistently incorporated**
- **Balancing importance of parameters through weighting factors**
- **Transparent results providing basis for**
  - identification of important parameters
  - discussion of assumptions made
  - explanation of reasons for recommending one option
  - communicating the results and recommendations
- **Sensitivity analysis shows stability of resulting recommendation for decision**

General Conclusion

optimisation approaches

- based on realistic risk estimates
- effective use of resources
- reference / alternative scenarios

uncertainties

- deterministic sensitivity analysis
- use of probabilistic approaches

cost-benefit analysis

multi-attribute analysis

- assessment of cost efficiency
- inclusion of qualitative factors