IAEA
International Atomic Energy Agency

14. Case study 9:
The optimization implementation in an underground uranium mine

Optimization and Uranium mine : Course plan

To illustrate the implementation of optimization in a Uranium mine, the course will be divided into two parts

Part 1: General introduction to Uranium mines and corresponding exposure types

Part 2 : One example of optimization to radon exposure in an underground Uranium mine

Part 1: General introduction to Uranium mines and corresponding exposure types

Mine is a facility that produces or has the potential for production of raw materials of interest – ores of uranium, thorium or other minerals- that can be processed economically to recover the mineral.

Mineral content or grade of the ore, thickness and extent of the ore body, amenability of the ore body to introduce mining machinery affect the mining method and associated radiation protection program.

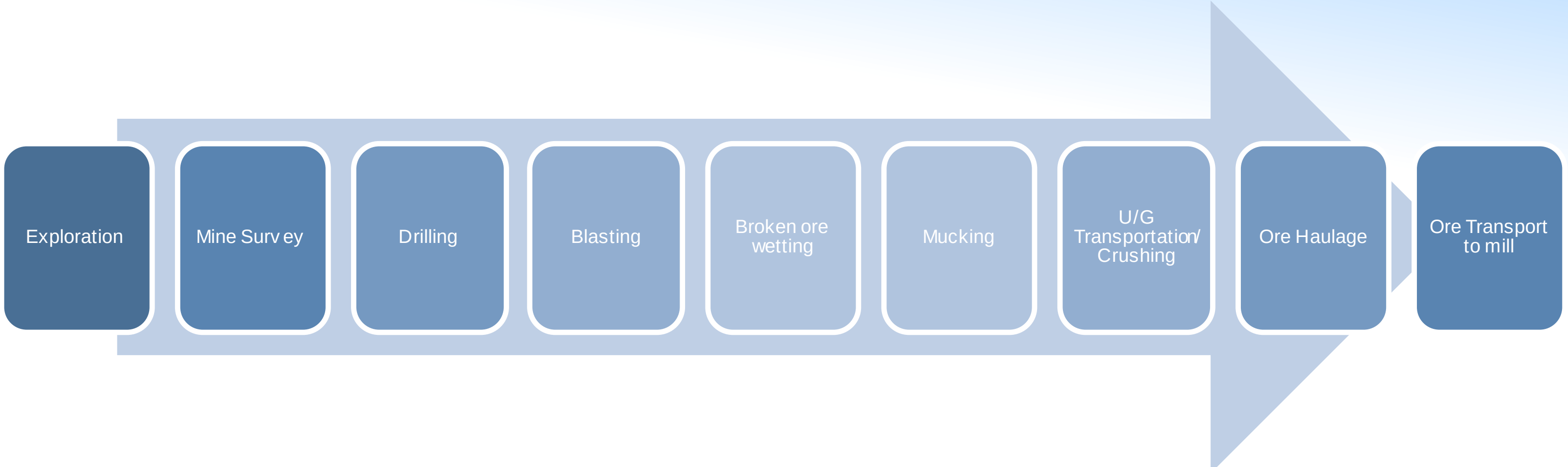
Underground Mining

If a large ore body is located below ground, underground mining methods are used.

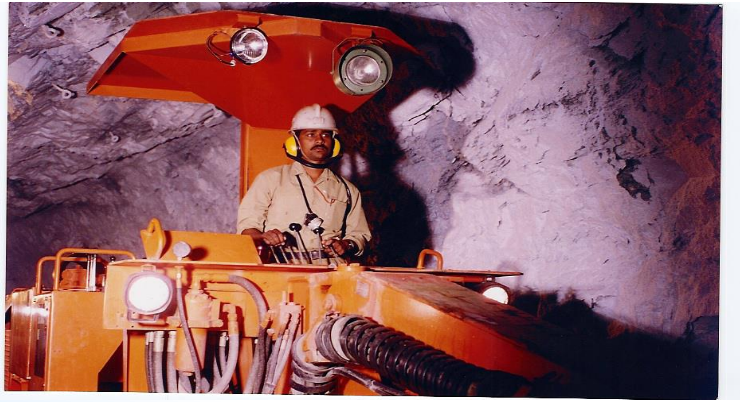
Entry to an underground (U/G) mine may be through adits (horizontal tunnel), inclined passage or through a vertical shaft or a combination thereof.

Each mine has individual peculiarities requiring sound engineering, ventilation principles and radiation control system.

Mining Operations



- Exploration
- Mine Survey
- Drilling
- Blasting
- Broken ore wetting
- Mucking
- U/G Transportation/ Crushing
- Ore Haulage
- Ore Transport to mill



Some operations in recent mines

Drilling Operation in Mines (Hydraulic Jumbo Drill)

Ore Loading and Haulage Operation

Sources of Radiation in Mining and Processing of Raw Materials

Main Sources of Radiation are:

- Gamma radiation from uranium and thorium decay chain in ore body and process facilities (Mills)
- ^{222}Rn, ^{220}Rn and progeny in mines, mills, tailings facilities and environment
- Uranium and/or thorium ore dust in mines, mill and tailings facilities

Gamma radiation

Gamma radiation in mines and mill are proportional to the ore grade

Dose rates in mine

D (mGy.h^{-1}) = 50 x C

Where C is ore-grade (% U_3O_8)

Air borne contamination

Radioactive ore dust gets airborne during mining and milling operations.

Radon/ Thoron and short-lived progeny get airborne and assume importance in underground mining.

Surface contamination

Surface contamination in mine is relatively less important due to presence of large quantity of ores itself

Surface contamination on equipment in high grade ore mining is important

Surface contamination becomes a source of external radiation and internal exposure due to inhalation of re-suspended activity

Ventilation is very important …

Design of ventilation system should be integral part of mine “establishment”

Primary ventilation system should provide fresh air at workplaces and dilute airborne contaminants

Auxiliary ventilation through flexible ducts should be provided to supplement primary ventilation whenever required

Positioning of auxiliary ventilation duct should be such as to avoid recirculation of contaminated air

… as well as individual protective equipment (IPE)

Protective clothing include coveralls, head coverings, gloves, boiler suits, impermeable footwear, aprons and reinforced clothing,.

Personal protective equipment should be selected considering the hazards involved, convenience and comfort in use

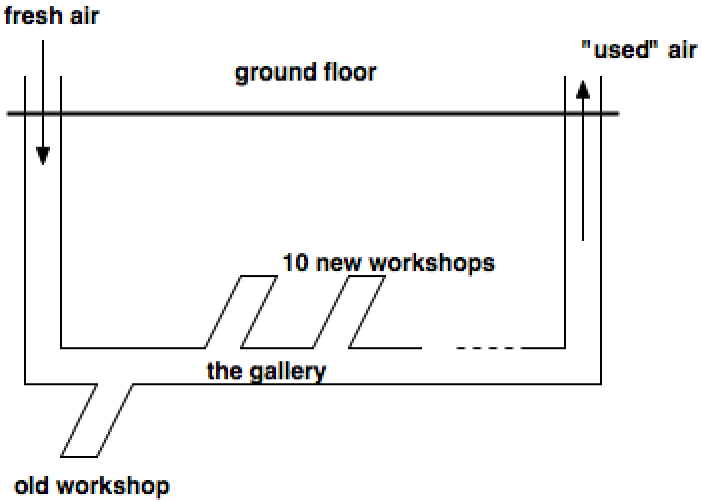
Workers who may have to use such equipment should be properly trained in its use, operation, maintenance and limitations

Mining and processing facilities are assumed to fall automatically within the scope of regulation: workers exposures have to be formally optimised

Just as a reminder : within the recommended regulatory graded approach

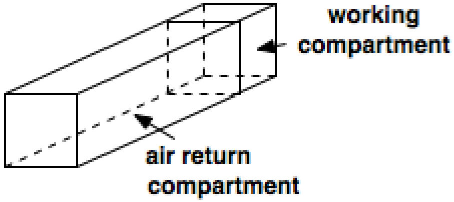
Mining and processing facilities are assumed to fall automatically within the scope of regulation: workers exposures have to be formally optimized

Part 2: example of optimization of occupational exposure in an underground copper mine



In that mine one workshop is now abandoned, the vein being exhausted

While the 17 workers have now to work into ten new places



Each workshop may be divided Into 2 compartments

Inhalation from radon and progenies: the main component to be optimized ?

In that mine the three main components of occupational exposure are: *external gamma irradiation,*alpha contamination due to long life dusts,*and alpha contamination due to radon and its short life progenies

The external component, while being assessed as part of the individual exposure, will not give rise to radiological protection options (no available technical solution at a reasonable cost at the time of the study)

Therefore all options will be devoted to reducing alpha contamination

Why not to take care of both internal and external in the optimization process?

Here the external component has been assessed only in order to be able to be added to the internal at the individual level in order to check if the limit is not exceeded after the optimization of the inhalation, which will be performed making use of the collective dose.

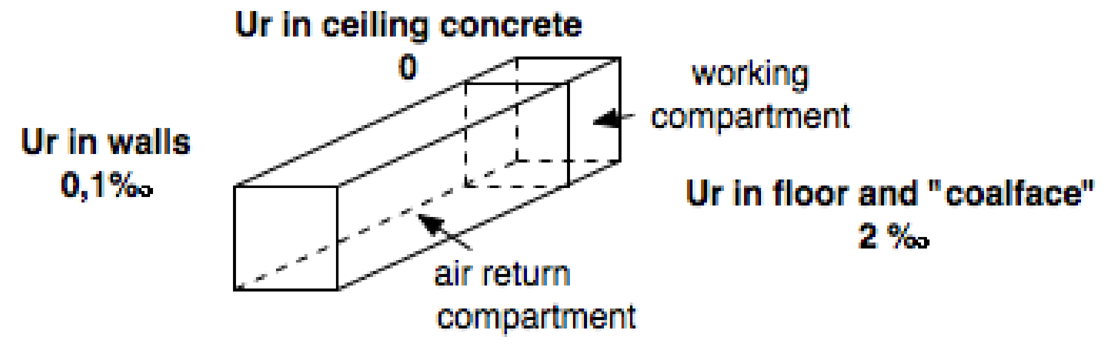
It therefore introduces a constraint for the optimization, which has to be fulfilled whatever the cost, whatever it is reasonable or not.

Could you envisage today options dealing with the external component?

Assessment of the external component?
The Uranium contents

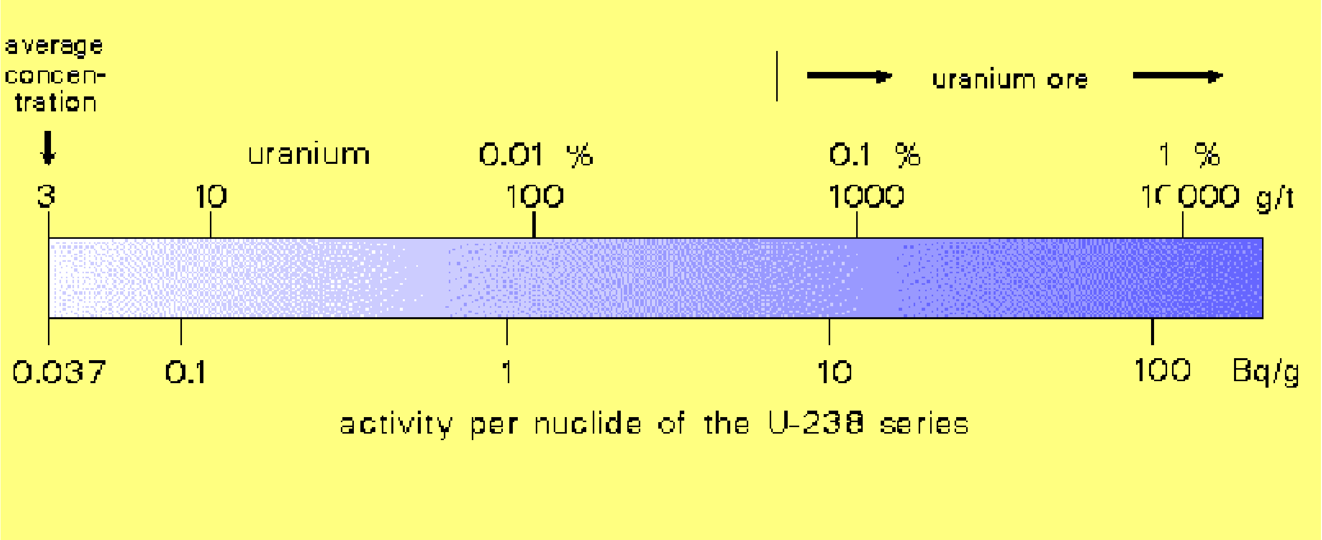
In the gallery, the Ur represent 0,1‰ in all faces

In the workshop (stope) it depends on the face as shown on the figure



This has allowed to calculate dose rates in the different areas

Uranium concentration in rocks and ores



Assessment of the external component?
The workload

		% of workload in		
specialty	Number of workers	Work compartment	Air return compartment	gallery
borer	4	100		
loader	4	25	25	50
bolter	2	50	50	
drainer	2	50	50	
handyman	3	25	25	50
leader	2	25	25	50

Assessment of the external component? The individual doses

Making the assumption of 2000 hours of work per year in each area leads, for one worker staying all time at the same place, to the following doses:

In the gallery:	2,0 mSv / year
In the air return compartment	6,6 mSv / year
In the work compartment	9,0 mSv / year

Under the previous assumptions of workload breakdown the annual effective dose for each worker due to external exposure should be:

borer	9,0 mSv / year
bolter and drainer	7,8 mSv / year
others	4,9 mSv / year

So this is the assessment of : the external component only; it should be added to the internal to understand the real stakes

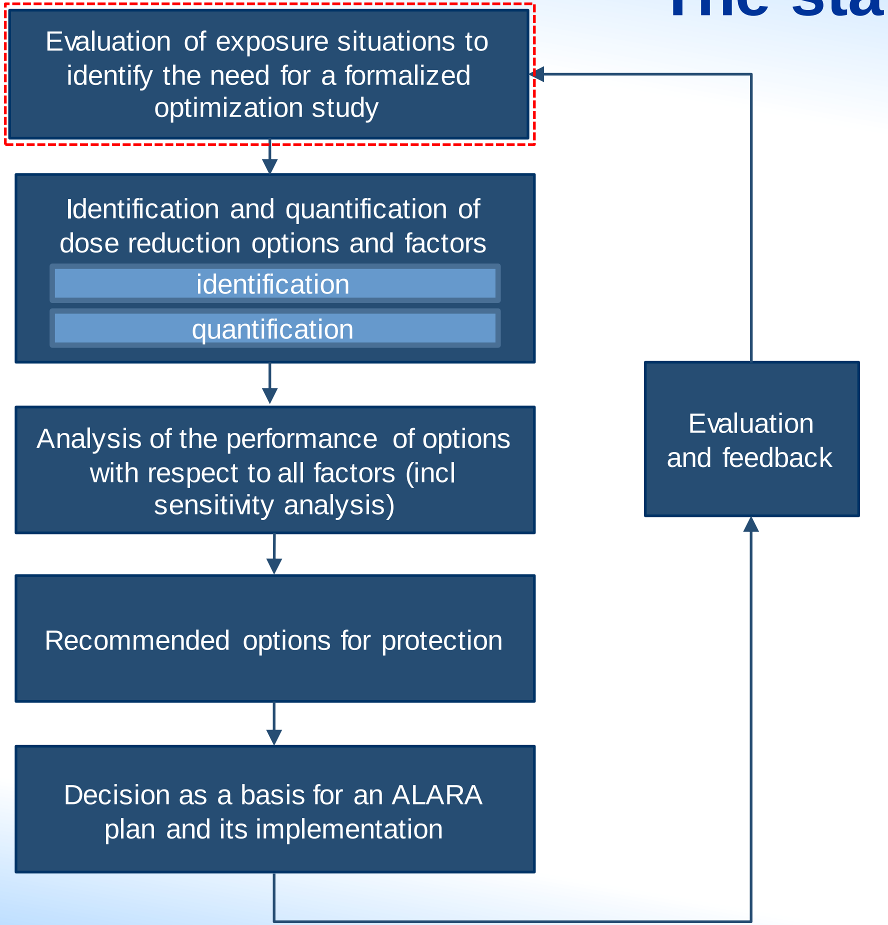
Assessment of the internal component? The individual doses

Having in mind that it is mandatory for breathing to have a minimum of ventilation both in the gallery and in the workshops, which means that the “reference option” will automatically include such ventilation as good practice

Making use of models calculating the energy alpha and the efficient dose per hour

It has been possible to estimate that the internal dose may exceed easily, if no protection action, 50 mSv per year for many workers

The stakes ?


Evaluation of exposure situations to identify the need for a formalized optimization study

Identification and quantification of dose reduction options and factors

identification

quantification

Analysis of the performance of options with respect to all factors (incl sensitivity analysis)

Recommended options for protection

Decision as a basis for an ALARA plan and its implementation

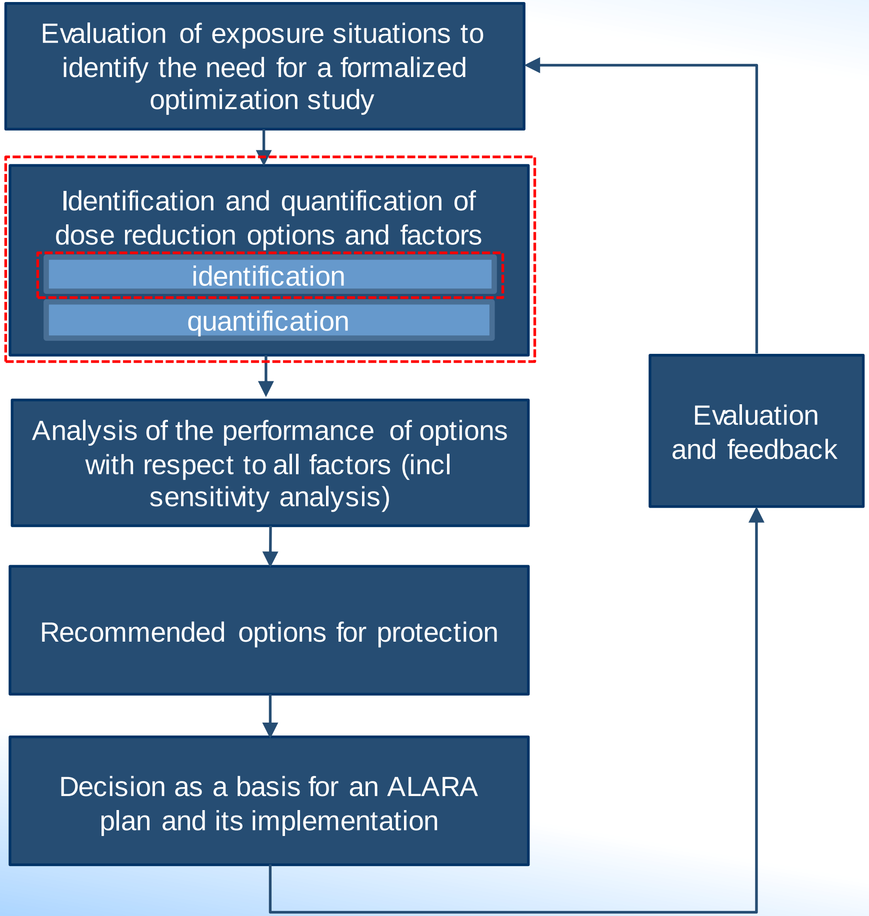
Evaluation and feedback

Individual internal exposure may exceed easily 85 to 100 mSv per year for all workers

Having in mind the already calculated 5 to 10 mSv per year from the external exposure

There “was” an obvious need for a high formalized implementation of the optimization procedure, spending time, brainstorming with several types of stake holders (engineers; work planners, RPO’s, …)

Possible envisaged options



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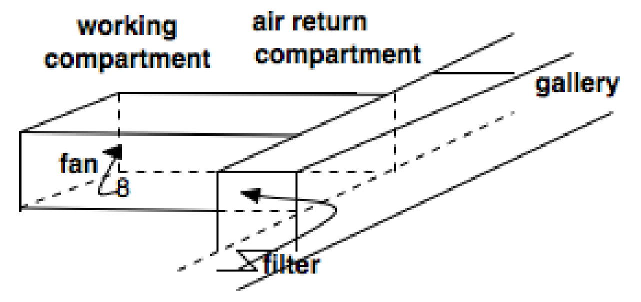
To close or not the old workshop in building a concrete wall (2 options)

To act on the primary ventilation system (in the gallery): the reference being 20 m^3/s; one can envisage 3 other options modifying it up to 30, 60 or even 120 m^3/s (4 options)

To act on the secondary ventilation system from each workshop (stope) to the gallery with ventilation rates of 3, 5 11 m^3/s (3 options)

The possible envisaged options

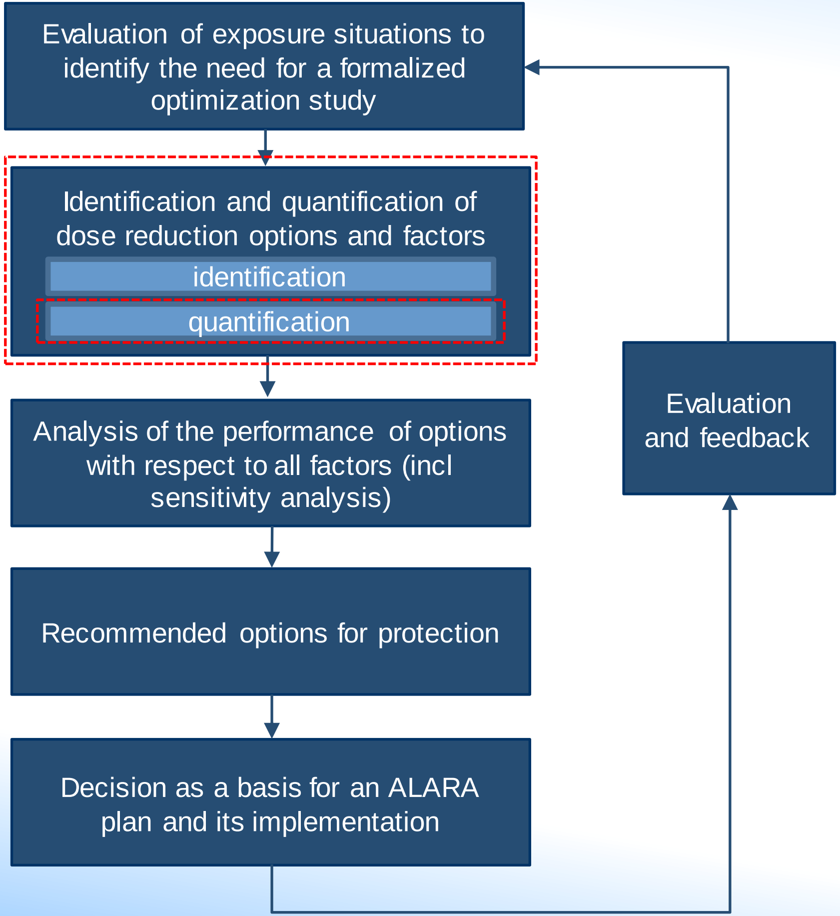


To install or not a small fan to reduce air stagnation in the cul de sac from each stope (2 options)

To install or not electrostatic filters to eliminate progenies of radon in the primary air from the gallery to the workshops; the filters may have from 1 to 4 cells (5 options)

So there are 12 different options including reference and 240 combinations of options (2*4*3*2*5).

Quantifications of options



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Evaluation and feedback

The impact of each option and combination of options have been estimated both from the internal dose reduction and increase of costs aspects

Quite complex models were developed for assessing the internal doses; the reference option being corresponding to more than 7 man.Sv collective dose over a ten years period

An extended cost analysis was performed that will be presented now

The cost elements for each option

Option	Investment cost In k€	Annual operating costs in k€
Concrete wall	5,52	0
Primary ventilation *ref 20m^3/s*	26,88	22,08
30m^3/s	27,84	54,24
60m^3/s	50,88	117,6
120m^3/s	101,76	235,2
Secondary ventilation *ref 3m^3/s*	4,8	8,16
5m^3/s	10,08	18,24
11m^3/s	23,04	67,2
Fan	3,12	2,448
Filters		
1 cell	7,44	0
2 cells	14,88	0
3 cells	22,32	0
4 cells	29,76	0

Hypothesis for calculating the total cost per option over a 10 years period

The operating period for the cost efficiency study was 10 years.

One workshop lasts around 6 months, then a new one must be open

Therefore 20 walls should be built on a ten years period.

The filter cell life is 2.5 years. So there is a need of 4 renewals per workshop during ten years, but for being quiet 6 are needed which means 60 filters for ten workshops.

The ventilation secondary systems are supposed to last 10 years, so 10 should be needed plus 2 in case of failure.

No extra ventilation system is required for the primary ventilation.

Under these assumptions can you calculate the total cost for each option? making use of Excel if you have it.

Total cost for each option over a ten years period

Option		Total cost (In k€)
1 Concrete wall		110,4
0 Primary ventilation	*ref 20m³/s*	247,68
2	30m³/s	570,24
3	60m³/s	1226,88
4	120m³/s	2453,76
0 Secondary ventilation	*ref 3m³/s*	139,2
5	5m³/s	303,36
6	11m³/s	948,48
7 Fan		61,92
Filters		
8	1 cell	446,4
9	2 cells	892,8
10	3 cells	1339,2
11	4 cells	1785,6

Cost efficiency analysis

The total cost and efficiency (in terms of alpha contamination) of all the 240 combinations of options have then been calculated.

The combination were ranked by increase level of costs.

All combination leading to higher cost and no reduction of dose, were suppressed as not cost efficient.

At the end only 8 combinations of options different from the Reference appeared to be cost efficient.

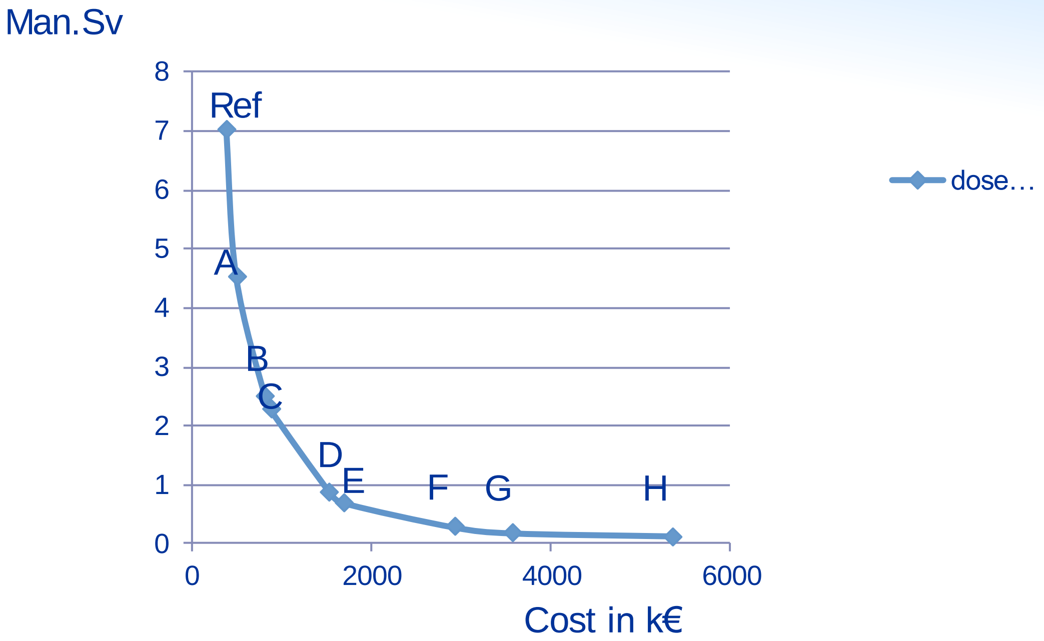
Cost efficiency analysis

Combination	Wall	Prim Vent	Second vent	Fan	Filter
R reference	No	20	3	no	no
A Reference +1	yes	20	3	no	no
B 1+2+ref second	yes	30	3	no	no
C 1+2+ref second+7	yes	30	3	yes	no
D 1+3+ref second+7	yes	60	3	yes	no
E 1+3+5+7	yes	60	5	yes	no
F 1+4+5+7	yes	120	5	yes	no
G 1+4+6+7	yes	120	11	yes	noH
H 1+4+6+7+11	yes	120	11	yes	4

Doses and costs of the remaining combinations of options

Options combination	Collective dose	Cost
R reference	7,04	386,88
A Reference +1	4,54	497,28
B 1+2+ref second	2,5	819,84
C 1+2+ref second+7	2,28	881,76
D 1+3+ref second+7	0,89	1538,4
E 1+3+5+7	0,7	1702,56
F 1+4+5+7	0,29	2929,44
G 1+4+6+7	0,19	3574,56
H 1+4+6+7+11	0,14	5360,16

The cost efficiency curve



Cost efficiency analysis exercise

Making use of the previous table (dose and cost)

- Calculate the cost of the avoided man Sievert for each combination
- To what combination (s) do you compare the others?
  - Always to the reference?
  - To another combination? Always the same?
- What happens if you have a maximum monetary value of the man.Sievert equal to 2000 Euros?

The cost effectiveness ratios

Options combination	Collective dose man.Sv	Cost k€	Delta cost k€	Delta dose man.Sv	Cost effective. Ratio K€ per man Sv € per man.mSv
R reference	7,04	386,88			
A Reference +1	4,54	497,28	110,4	2,5	44,2
B 1+2+ref second	2,5	819,84	322,56	2,04	158,1
C 1+2+ref second+7	2,28	881,76	61,92	0,22	281,5
D 1+3+ref second+7	0,89	1538,4	656,64	1,39	472,4
E 1+3+5+7	0,7	1702,56	164,16	0,19	864,0
F 1+4+5+7	0,29	2929,44	1226,88	0,41	2992,4
G 1+4+6+7	0,19	3574,56	645,12	0,1	6451,2
H 1+4+6+7+11	0,14	5360,16	1785,6	0,05	35712,0

The optimal combination of options

With regards to the man.Sievert monetary value of 2000 Euros the

Optimal combination of options is E

The wall should be built to close all “old workshops”

The ventilation increase is also obvious both for primary and secondary but it should be stopped at 60 m^3/s and 5m^3/s respectively

The fan should be installed

On the contrary the filters even if very efficient appear to be too expansive

Do the optimisation fulfil the other requirements?
Coping with dose limits? In agreement with other risks?

The optimal combination of options: does it fit with dose limits?

Options combination	Indiv dose Borer `mSv/year	Indiv dose Bolter and drainer mSv/year	Indiv dose Others mSv/year
R reference	111.7	98.6	86.8
A Reference +1	81.6	68/9	57.8
B 1+2+ref second	56.8	44.6	34.2
C 1+2+ref second+7	51.9	41.9	32.7
D 1+3+ref second+7	35	25.3	16.8
E 1+3+5+7	31.6	22;5	15.3
F 1+4+5+7	26.6	17.7	10.7
G 1+4+6+7	24.6	16.2	9.9
H 1+4+6+7+11	23.9	15.4	9.5

We can see that dose limits are exceeded in combination E for three categories of workers

The optimal combination of options: it does not fit with dose limits

Clearly looking at these results one should to go further for reducing dose whatever the extra cost in order to be sure not to exceed the dose limit.

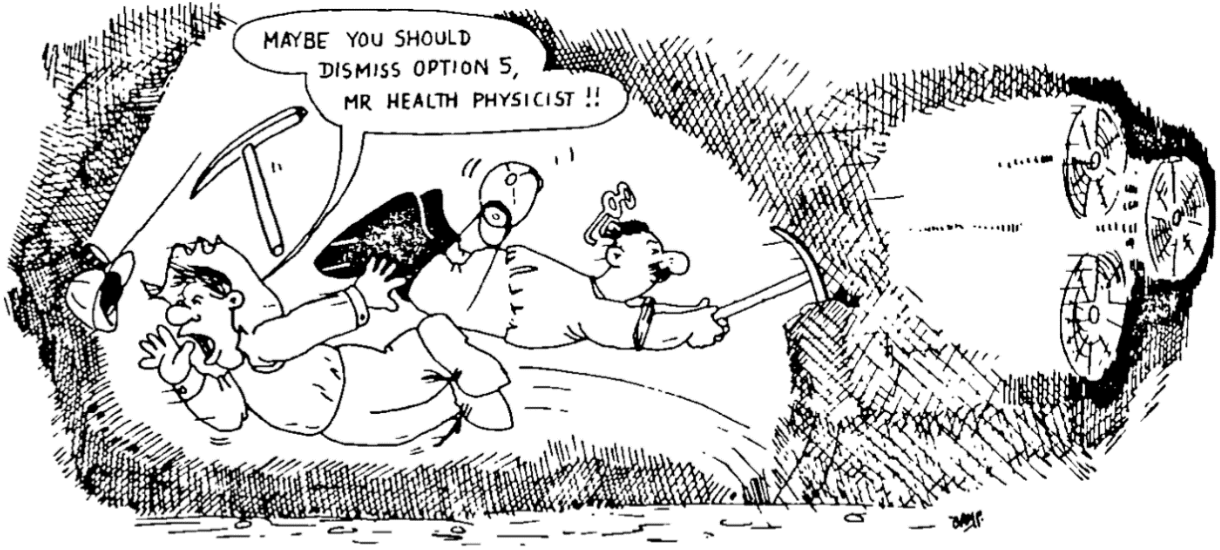
However here the first question to be asked for is:

What should have happened in the optimization process if the hypothesis would have been less conservative and more realistic?

A second question is : what should be the optimization result with a higher man Sievert monetary value ?

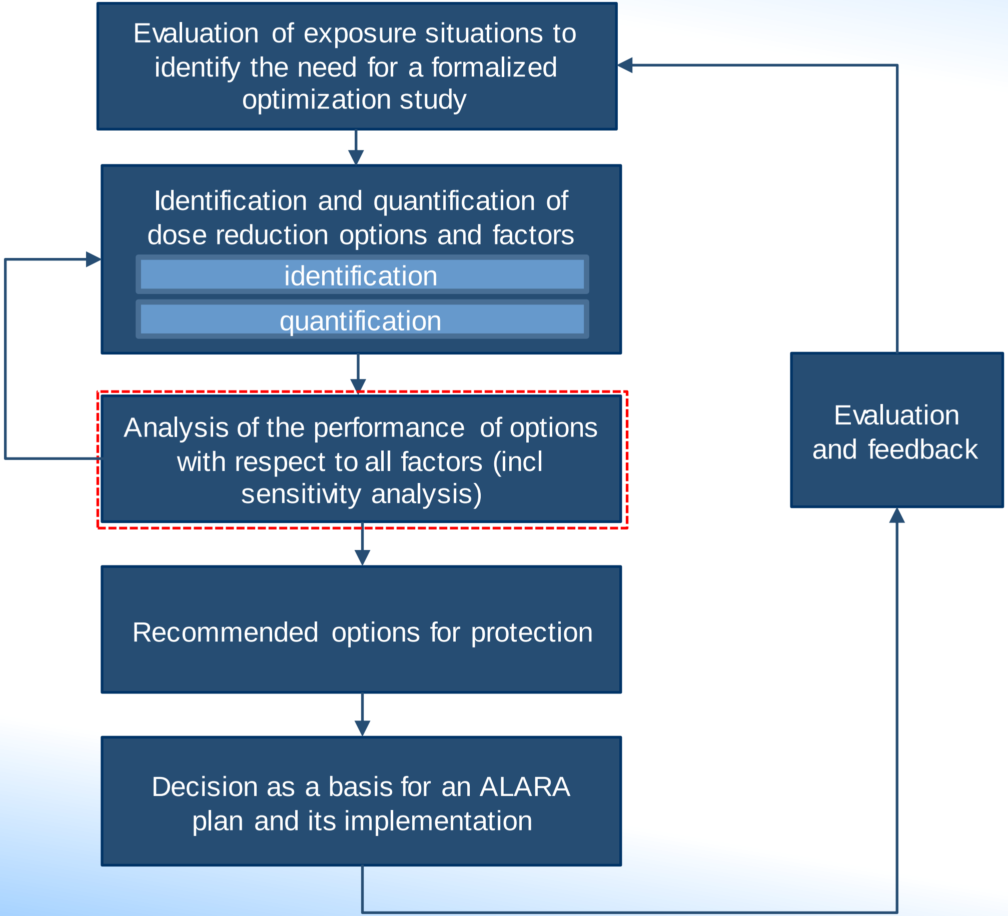
When making use of the one of 10000 € per man mSv from a reprocessing plant then the combination G should be the optimal one, but even that would not fit with the dose limit. And then also it is not sure that all options were adapted if looked at through other criteria

Dismiss that option mister health physicist!



The levels of dose and the financial costs may not be the only relevant factors - Example of ventilation measures in a uranium mine.

Optimization is an iterative process



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Identification and quantification of dose reduction options and factors

- identification
- quantification

Analysis of the performance of options with respect to all factors (incl sensitivity analysis)

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Evaluation and feedback

Here it is mandatory to go back to the previous step and to identify other options

What if?

Other options might be envisaged

What kind of options would you suggest?

Other options?

The production process itself shall be questioned and not only the protections?

Therefore all types of stakeholders should intervene in the brain storming and be coordinated by the health physicists or the designers

Is it foreseeable to envisage a quasi *no entry* in the working compartment ? Allowing the borers to work at distance?

Can we envisage that more mechanised tools or robotics, even if increasing the investment costs will lead to a decrease of the operating costs per produced ton, that should led to the “reasonable” part of the optimization?

Should it be worthwhile to have higher man sievert monetary values in the mines due to the stakes and working conditions?

Conclusions

That example has shown that

The assessment of doses shall be as realistic as possible (already said several times and in particular for all NORM presentations)

The optimization process is an ongoing process which will never be to its end, any time the context both technical, social economical has evolved one can think about a review of what was considered up to then as optimized.

The optimization process cannot be performed by the health physics and RPO people alone, there is often a need for the participation of many other types of stakeholders within the company

Finally, as already shown in many examples the optimization process shall take into account much more than the only cost and efficiency criteria

Annex : Lecture -3 from IAEA PGEC

IAEA

Individual Protection and Specific Equipment
&
Security of sources

Personal protections

Respiratory protection

- Respirators
- Facemasks
- Breathing apparatus

Use of respirator should be supervised to ensure -

- Proper fitting
- Low breathing resistance
- Short term use only
- Regular cleaning and maintenance

Program for respiratory protection should be acceptable to the regulatory body

Respirators

Personal Protective Equipment (1)

Personal Protective Clothing (2)

Personal Protective Clothing (3)

Measurement of Radioactivity and Radiation

Measurements of radioactivity and radiation are carried out at workplace and in the environment using various devices

Measurement of radioactivity:

- Alpha activity counters
- Radon and progeny counters
- Beta activity counters
- Gamma counters

Radiation measuring survey meters:

- GM Counters
- Proportional counters
- Scintillation detectors

Radioactivity counters

- Beta measurement : GM counter
- Alpha measurement : ZnS (Ag) detector
- Air activity : Air samplers and radioactivity counters
- Rn/Tn and progeny measurement :

  Air sampler

  Scintillation cell

  Low Level Radon Detection System

  Double-filter method

  Alpha Guard

  RAD7

Surface Contamination monitor : Alpha Scintillation counter

Beta surface counter

Radiation monitoring instruments

Radon Monitor

Contamination Monitor

Dose rate Monitors