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Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Dose-LCA for nuclear and wind energy electricity production

Does wind energy production cause more radioactive doses than nuclear power plants?

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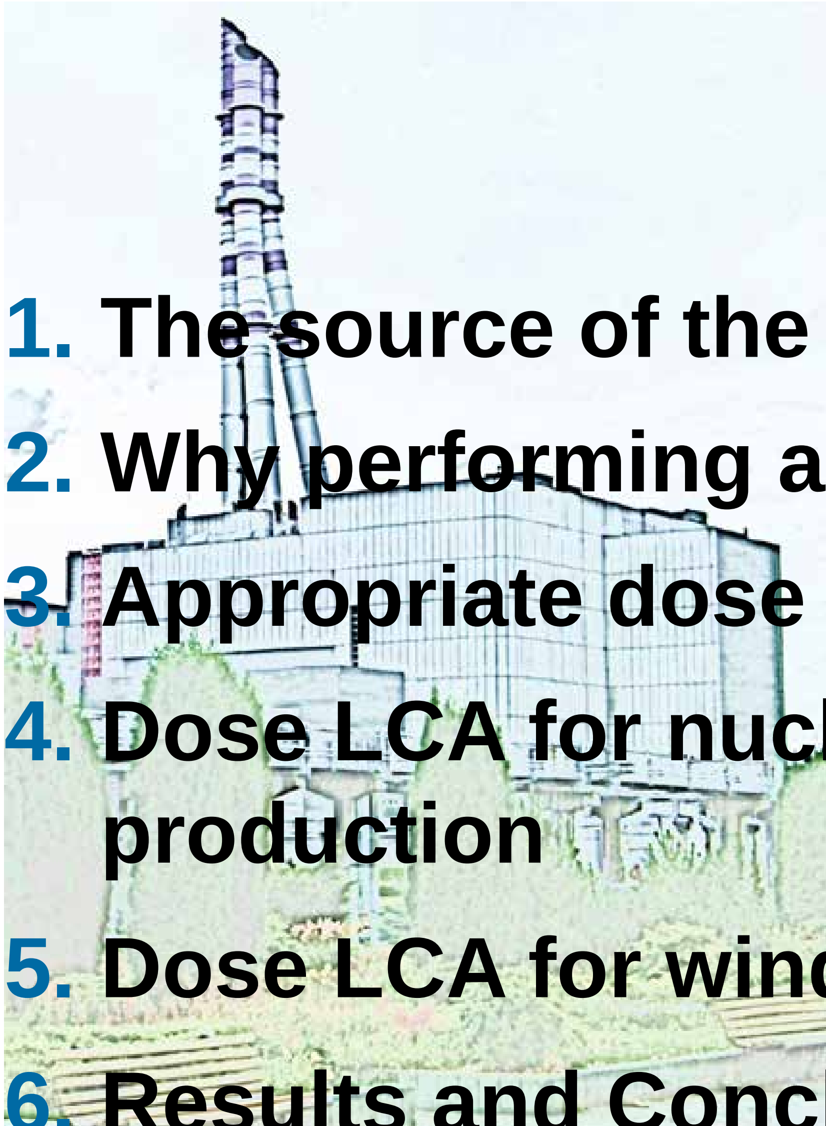
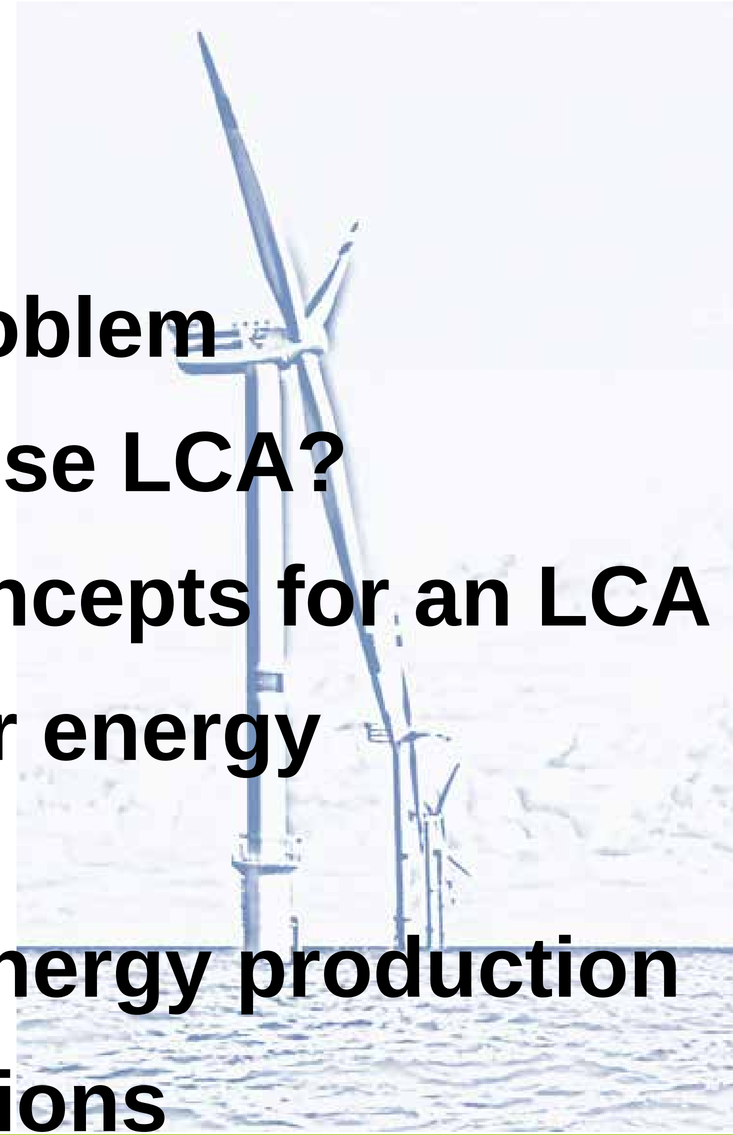
Overview





1. The source of the problem
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1. The source of the problem

- Modern gearless wind turbines with large energy production capacities per plant (e.g. 5 MW offshore) use permanent magnets with an alloy of neodymium, praseodymium, boron and iron to achieve high efficiency at smaller weight and volumes.
- The production of the rare earth elements neodymium and praseodymium is always associated with an elevated thorium and/or uranium content in these ores, so their production and waste management can be associated with radioactive doses.

Average and maximum concentrations of U, Ra-226 and Th in Chinese rare earth ores (from: Liu Hua 2011)

Elements/ mineral	Concentrations of Natural Radionuclides						External γ dose rate (nGy/h)	
	Uranium, Bq/Kg		^{226}Ra (Bq/Kg)		Thorium (Bq/Kg)			
	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.
Rare earths	3972	78000	2529	30200	5782	137000	5709	32671

1. The source problem

Concentrations of U and Th in some rare earth ores worldwide:

Country	Site	Company	ppm U	ppm Th	Bq U / g	Bq Th / g	EU(Building) without K-40	Re-mark
Sweden	Norra Kärr	Tasmanmetals	14	7	0.174	0.028	**0.72**	
Greenland	Killavaat Alannguat	Tanbreez	10	25	0.124	0.101	**0.92**	
Malawi	Kangankunde	Lynas Corp.	?	46	?	0.187	**0.93**	+
Canada	Nechalacho	Avalon	29	160	0.361	0.649	**4.45**	
RSA	Zandkopsdrift	Frontier	47	178	0.585	0.722	**5.56**	
Canada	Strange Lake	Quest	?	280	?	1.136	**5.68**	+
China	Bayian Obo		?	300	?	1.218	**6.09**	+
USA	Mountain Pass	Molycorp	20	292	0.249	1.185	**6.75**	
Australia	Mt. Weld	Lynas Corp.	11	630	0.137	2.557	**13.24**	
Greenland	Kvanefjeld	Greenland Minerals	400	700	4.976	2.841	**30.79**	

"+" means: not including unknown U contribution

Source: own compilation from different sources

Conclusion:

- Nearly all concentrations of U and Th in REE ores exceed the EU standard for the use of the material as building material.
- The production of REEs is associated with radioactive doses.
- So the question arises: Are those in a relevant extent?

2. Why a dose LCA?

- Life Cycle Assessment: to account for all (environmental, health, social, economic ...) effects that production and use of a product is associated with (environmental footprint)
- Holistic approach: From cradle to grave, total „product chain“
- Wider responsibility: assumes that producing a good (producer‘s view) or buying/using a product (consumer‘s view) means taking over responsibility for all positive and negative consequences; assumes that the distribution of responsibilities between different parties within the chain should not dilute responsibilities to beyond any recognition
- LCAs are state-of-the-art, have an own ISO standard (14040), are widespread (e.g. as „carbon footprint“, for toxic or acidic emissions), but unusual in the nuclear sector

2. Why a dose LCA?

ISO14040

- Goal
- Scope
- Inventory
- Impact
- Interpret-ion
- Reporting
- Critical Review

ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.

ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.

The intended application of LCA or LCI results is considered during definition of the goal and scope, but the application itself is outside the scope of this International Standard.

3. Appropriate dose concepts for an LCA

To answer the question whether nuclear or wind energy production is associated with the larger radioactive doses,

- a quantitative analysis of all relevant impacts has to be made, because comparing doses only in a qualitative way does not yield meaningful values,
- a comparison of individual doses also does not yield meaningful values because doses for single persons are on the same level (e.g. for the most exposed workers in a nuclear power plant and in the filter area of the cracking stage in a rare earth production plant are similarly affected),
- a concept has to be used that is a linear approximation of the total effects (of all persons affected, over the complete time period of effects, etc.) not only arbitrarily selected parts of the whole effects.

3. Appropriate dose concepts for an LCA

- Only the collective effective dose concept reflects such an approach as is appropriate for an LCA.
- The collective effective dose sums up all doses posed to all affected persons of a practice:

$$D = \Sigma (d * n) \text{ with:}$$

d = individual effective dose (Sv/a),

n = number of affected persons

in man·Sv / a

- The collective dose also accounts for small doses applied to a large number of persons (e.g. for several million people) or for small doses over a very long time (e.g. for waste disposal).
- Arguments brought forward against collective doses are all inappropriate (see attachment).

4. Dose LCA for nuclear energy production

- Dose calculation methods as develloped by UNSCEAR in 1993 for
  - gaseous and liquid emissions from nuclear power plants
  - emissions of radon and dust during uranium mining and after closure of tailings stacks
  - contributions of other stages of fuel production
- Dose calculation methods had to be develloped for
  - gaseous and liquid emissions from fuel reprocessing plants
  - liquid emissions from final disposal facilities

4. Dose LCA for nuclear energy production

Some of the nuclear LCA data can be taken from sources some had to be calculated exclusively.

UNSCEAR 1993

Uranium production

Occupational doses	Public doses: Emissions, Radon+Dust

Mill tailings disposal

Direct radiation	Public doses: Radon+Dust

Conversion & Enrichment

Occupational doses	Public doses: Emissions

Fuel production

Occupational doses	Public doses: Emissions

Reactor operation

Occupational doses	Public doses: Emissions

Own calculation necessary

Fuel reprocessing

Occupational doses	Public doses: Emissions

Interim storage

Occupational doses	Direct radiation

Conditioning

Occupational doses	Public doses: Emissions

Decommissioning

Occupational doses	Public doses: Emissions

Final disposal

Occupational doses	Public doses: Emissions

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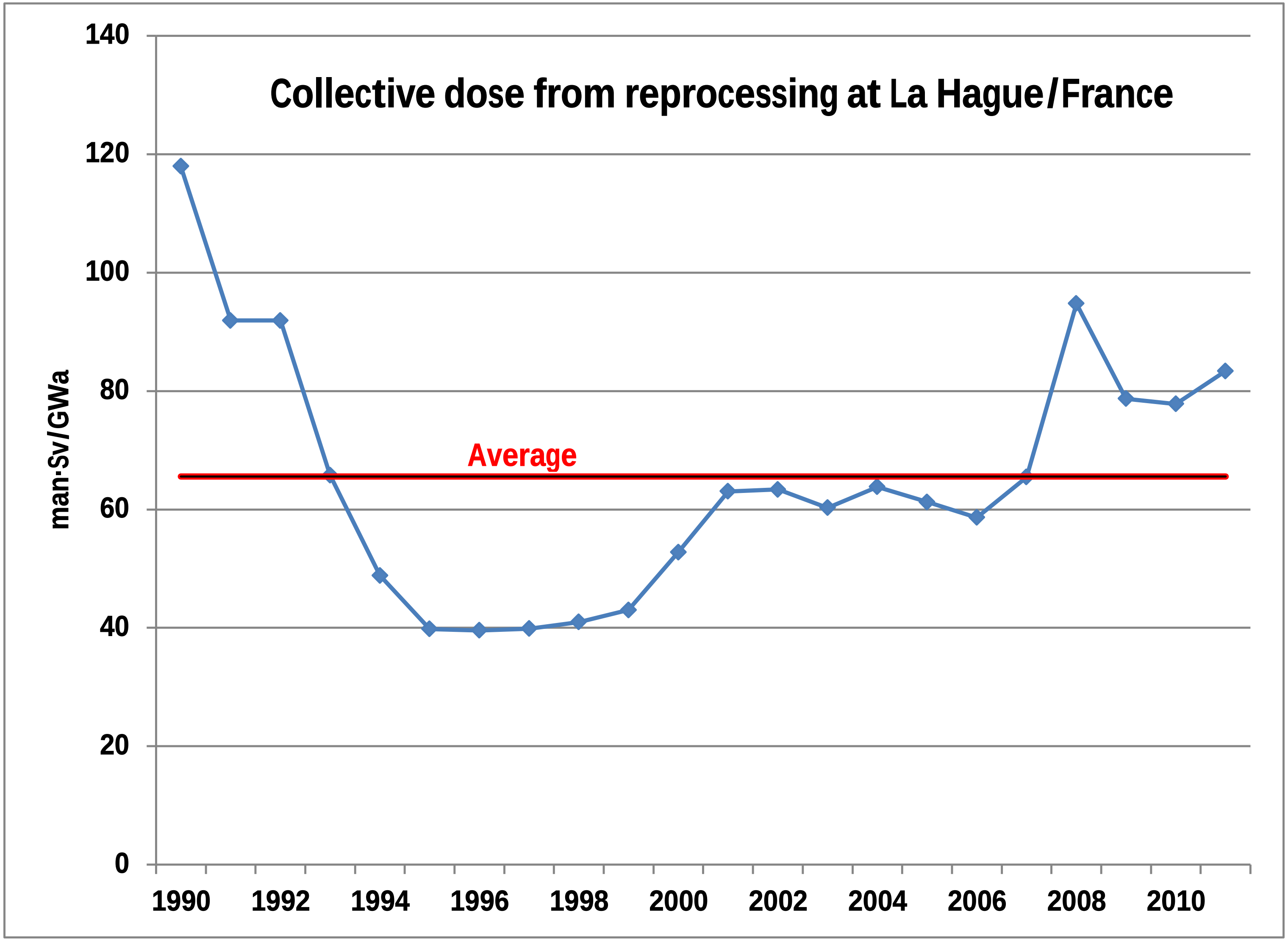
4. Dose LCA for nuclear energy production

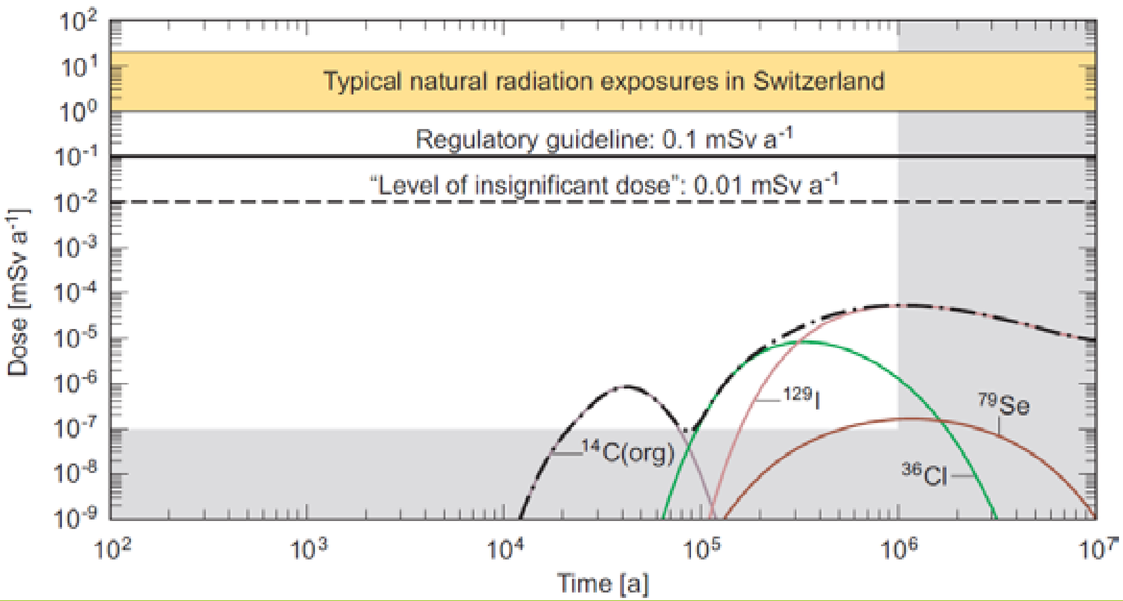


4. Dose LCA for nuclear energy production

Calculation of doses from final nuclear waste disposal:

Country	Final disposal project	Site	Host rock formation	Total dose Sv/Ma	Persons affected	Collective dose man·Sv/GWa
Belgium	(Research) SAFIR2	Mol	Boom clay	1,66	1000	22,46
Switzerland	Entsorgungsnachweis	Benken	Consolidated clay	0,20	1000	1,02
USA	Yucca M license app.	Yucca Mountain	Tuff	5,23	2400	5,17
France	Dossier Argile 2005	Bure	Consolidated clay	10,50	1000	6,51
Average				**4,40**		**8,79**

... was derived from long-term safety assessments by integration ...



... over 1 million years

Longer integration times (10 or 100 ma) do not change the results relevantly

Robust results, as necessary for a LCA

5. Dose LCA for wind energy production

Basic scenario:

- Production of Nd/Pr from Mt.Weld (Australia) ore (Lynas)
- Tailings from acidic ore digestion (WLP) with 5.9 Bq/g thorium
- Re-use of those 1.2m tons of tailings after dilution 1+6
  - in road construction
  - as coastal protection material

  as currently planned by Lynas
- City street, freeway, loss-of-material in building construction

D1-D4, Thornton Bank/Belgium, (C) Hans Hillewaert

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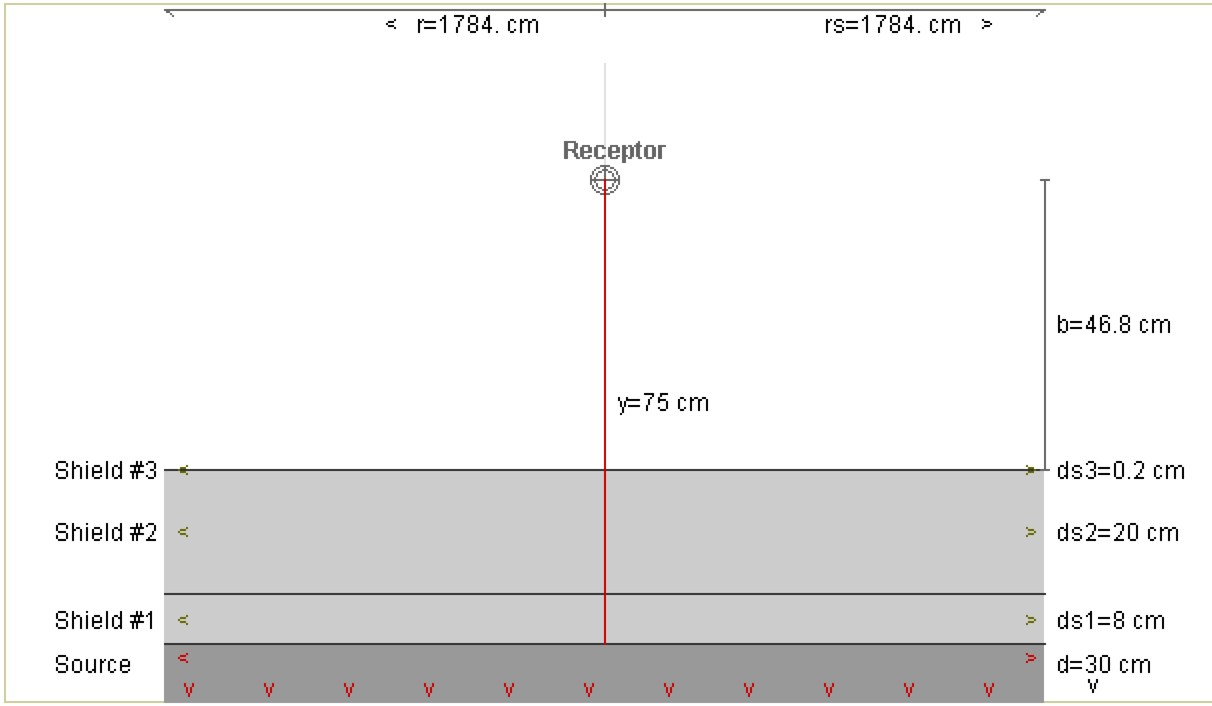
5. Dose LCA for wind energy production



Freeway scenario: Multi layer shielding calculation to get dose rates

Air layer

Car bottom steel layer

Air layer

Asphalt layer

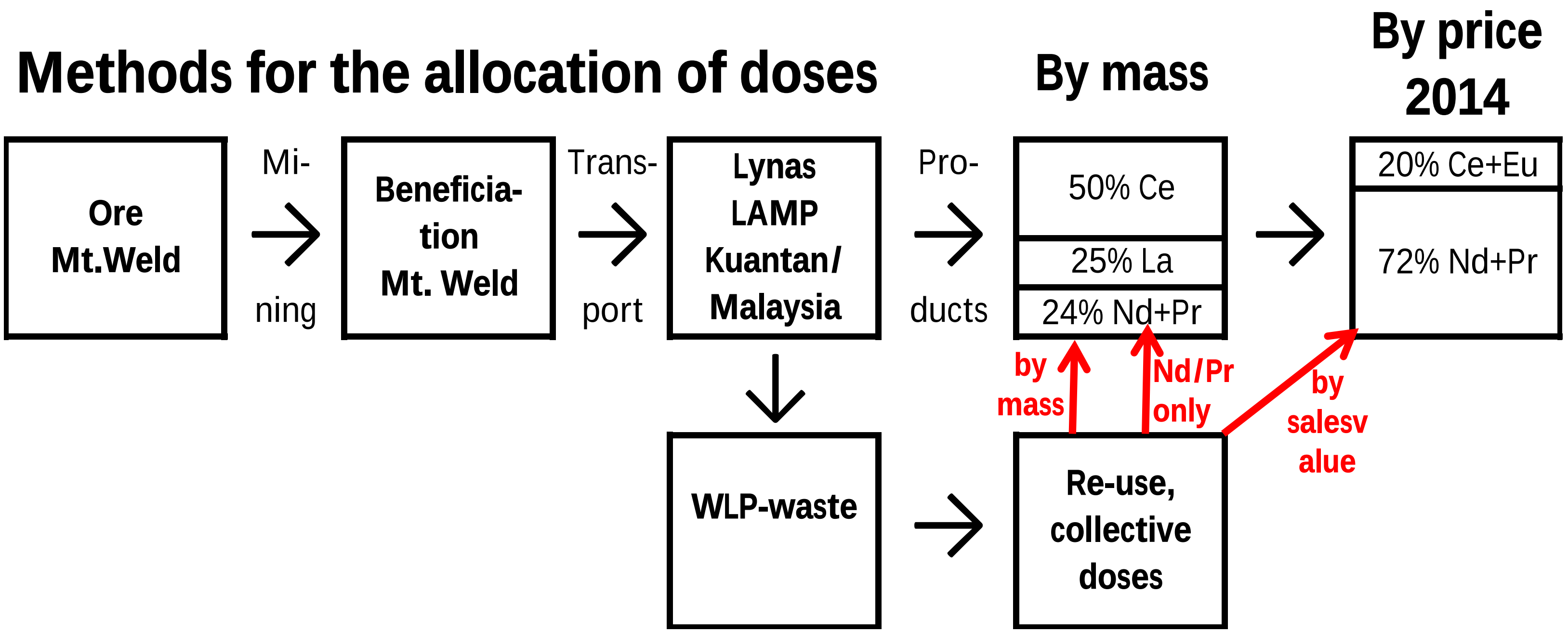
WLP-mix layer

Dose calculation:

- City street: 8.4 million ton of WLP mix, dose rate 65.41 nSv/h
- Freeway: 8.4 million ton of WLP mix, dose rate 64.7 nSv/h
- Loss-of-control: 10% loss to building industry, dose rate 358 nSv/h

5. Dose LCA for wind energy production

The dose attribution problem (typical for LCAs):



Dose attribution to a) produced mass of products, b) produced Nd+Pr only, or c) sales value of products yields different results!

But much more relevant for the dose is if the Nd/Pr is recycled (reduction by a factor of 10 theoretically possible).

6. Results and Conclusions

Nuclear	Minimum	Average	Maximum	Depending from …
Fuel supply	9		151	Performance of the tailings cover
Reactor operation	1,8	2	2,3	C-14 emissions
Fuel reprocessing	40	60	120	Optional, not needed
Final disposal of nuclear waste	1		22	Enclosure performance
Wind energy	**Minimum**		**Maximum**	**Depending from …**
Nd/Pr magnet, from Mt. Weld ore, attributed by mass	0		7	Re-use of mill tailings, recycling of Nd/Pr

6. Results and Conclusions

- LCAs are a powerful instrument to quantitatively assess the life-time impacts of a product (here: 1 GWa of electricity).
- The impacts can be assessed
  - from cradle to grave without leaving certain stages unrecognized,
  - not only on a local but on a worldwide basis,
  - over any timeframe: short-term effects as well as long-term effects.
- The results of LCAs make clear, which production stages contribute with the largest effects and which are of minor importance (nuclear: reprocessing and uranium mining; wind: waste management options, recycling).
- Dose LCAs provide a quantitative decision tool that up to today is not comprehensively applied.

Vielen Dank für Ihre Aufmerksamkeit!
Thank you for your attention!

Haben Sie noch Fragen?
Do you have any questions?

?

Arguments against the collective dose concept

Arguments brought forward against collective doses:

- „It is not scientifically proven that small doses cause health effects.“ The opposite, that small doses do NOT cause health effects either, can also not be scientifically proven. As long as this knowledge gap is not finally to be decided it is only wise to assume a linear-no-threshhold (LNT) approach and assume linear health effects for small doses.
- „Adding up small doses over a large number of persons or over very long timespans yields infinite collective doses.“ This is mathematically false, because the integration of radioactive decay curves (e.g. of carbon-14 with a halflife time of 5,730 years) always yields finite results and meaningful numbers.

Arguments against the collective dose concept

Arguments brought forward against collective doses:

- „Dose integration should be truncated below trivial dose levels, e.g. 10 µSv/a.“ That would mean to assume a threshhold below which the health risk is indeed and exactly zero. But in fact it is in the order of one-in-a-million and not exactly zero. The assumption that this truncation avoids running into infinity is unfounded.
- „In case of worldwide distribution of radionuclides, it is not known how many people will live in 20 years, so the number of affected persons is even less reliably known for 1,000 years or even longer.“ If the dose from a practice with today‘s world population is far above 18 man·Sv/a, this will not considerably change if one multiplies this with 10 or 100 for a rising population.

Arguments against the collective dose concept

Arguments brought forward against collective doses:

- „It is not known if mankind will still exist in 10 years nor if that is the case in 100 or 1,000 years.“ This case has been recognised by ICRP; and the answer is that people living in the future should be subject to the same risk and protection levels as today.
- „It is not known how people in 100 years or later will grow and take up food.“ The biological needs of the human body are well known and understood, the cultural and individual differences are existing, but are all within a relatively narrow bandwidth. As it is not necessary to calculate doses with a high accuracy, the results within this bandwidth of uncertainty are acceptable and meaningful.

Arguments against the collective dose concept

Arguments brought forward against collective doses:

- „For the small dose rates resulting from large dilution factors (e.g. in Lynas‘s case 1+6, or for discharges into the ocean) it is unsound to integrate those small effects.“ Dilution reduces the individual risk only, but increases the number of affected persons mostly linearly. So the total effects are not considerably decreased by dilution.
- „Natural background doses are often much higher than those from industrial practices.“ Yes, that is why the UN‘s scientific committee on the effects of atomic radiation UNSCEAR frequently evaluates those effects, too. But should risks be hidden behind higher risks? And especially behind those that can only be mitigated with large efforts, while reprocessing can easily be avoided?