# Use of Probabilistic Safety Assessment to Inform Detailed EPZs for SMRs

L Raganelli on behalf of H Stephenson and B Cirera

In collaboration with I Midoune at Imperial College London

PSMA14

crarisk.com

## The project

- This project was developed in collaboration with the following partners: Inayate Midoune at Imperial College London with supervision by my colleague B Cirera and K Ardron, Health and Safety Executive who provided the PACE software and MET office who provided weather data.

# UK background

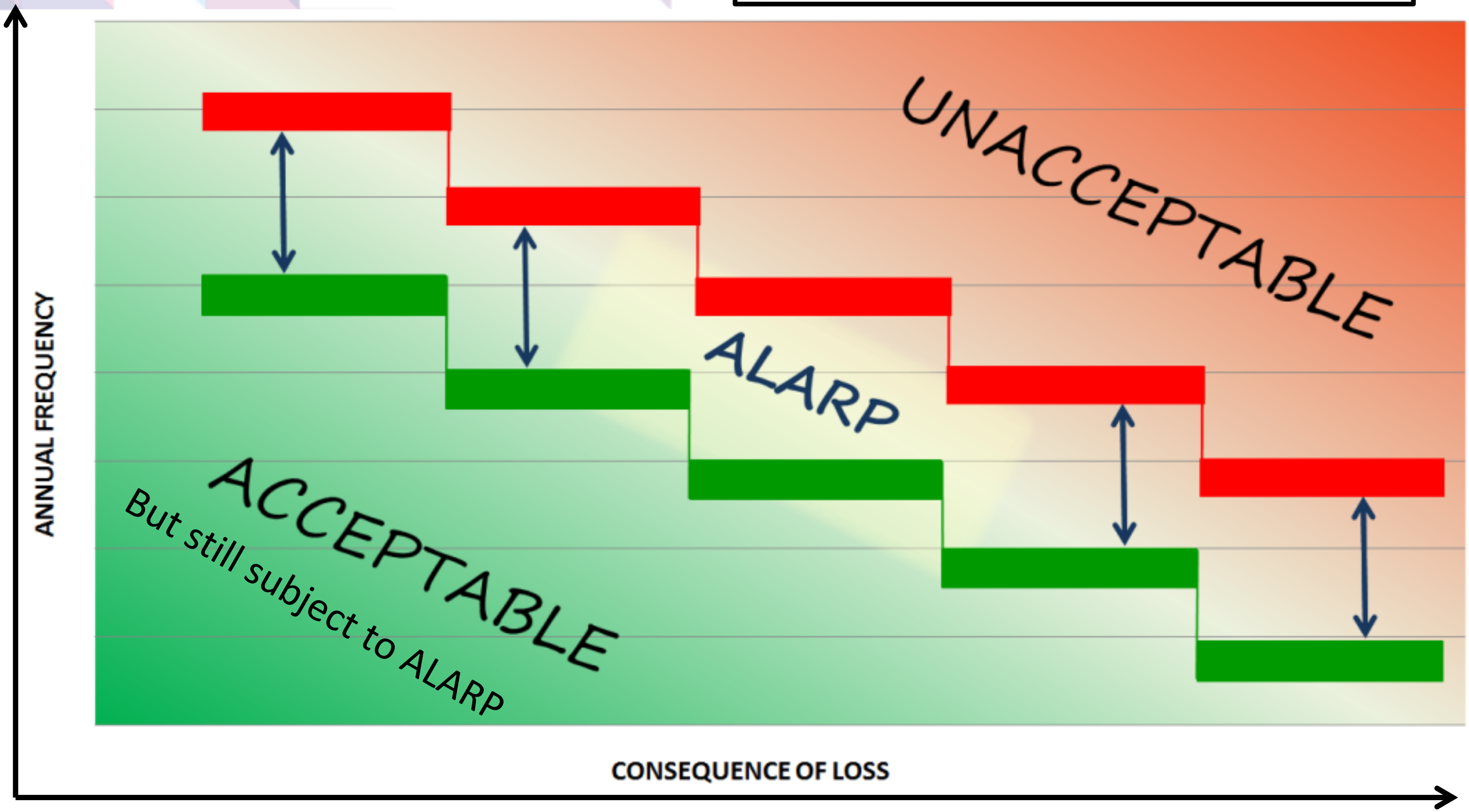
In the UK, the government is evaluating whether SMRs could potentially become a source of low $CO_2$, reliable energy generation. For this reason they have published a series of white papers and finally sponsored a preliminary GDA for 8 different SMR technologies.

UK regulator (ONR) doesn't adopt a target based safety approach but uses a 'low as reasonably practicable' (ALARP) approach

# ALARP approach

## What is Risk?

Risk = Frequency x Consequences



# ALARP approach

## What is Risk?

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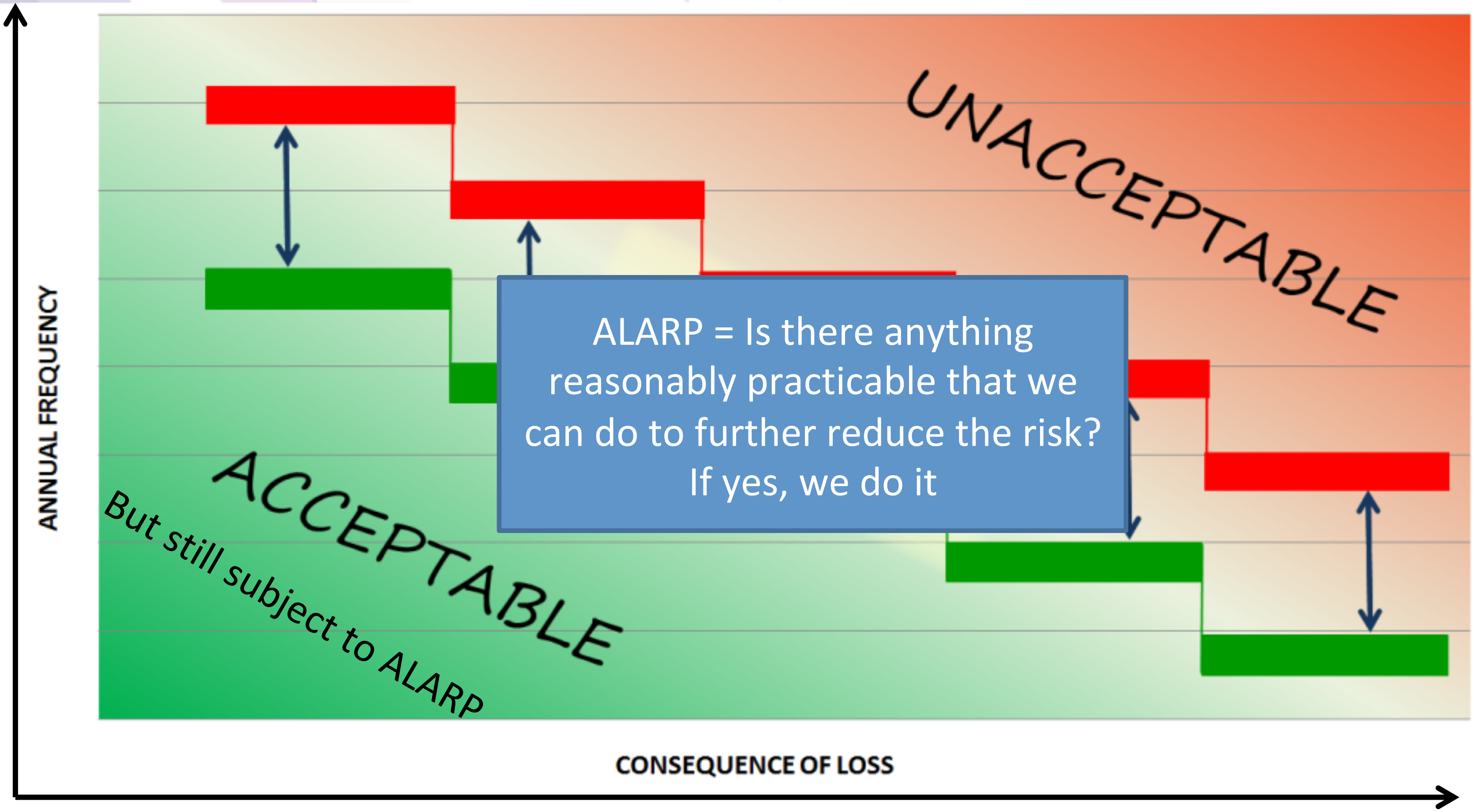


# Small Modular Reactors (SMRs)

- SMR = reactor generating less than 300MWe (IAEA)
- Could be built in factories to minimize initial capital costs of construction
- More passive safety
- Several designs under development, none licensed yet

| | |
|---|---|
| NuScale | 12 reactor modules, each 60 Mwe |
| Westinghouse SMR | 225 MWe |
| Holtec SMR-160 | 160 MWe |
| GenerationmPower | « two-packs » to « four-packs » modules, each 180 Mwe |

# The research questions

- Are the consequences of a radioactive release for an SMR worse or better than the consequences of a comparable release for a PWR of similar power?
- If the consequences for SMRs are worse/better, why is that?

- An SMR source term was compared with a 3.61% of the EPR (PWR) source term – this was to obtain equivalent thermal power outputs
- 2 specific accident source terms were chosen for EPR:
- RC702 - Steam Generator Tube Rupture without Fission Product Scrubbing
- RC802a - Small Interfacing System LOCA without Fission Product Scrubbing

# Why L3 PSA for SMRs

**Level 1**
Core Damage Frequency

→

**Level 2**
Radioactive releases

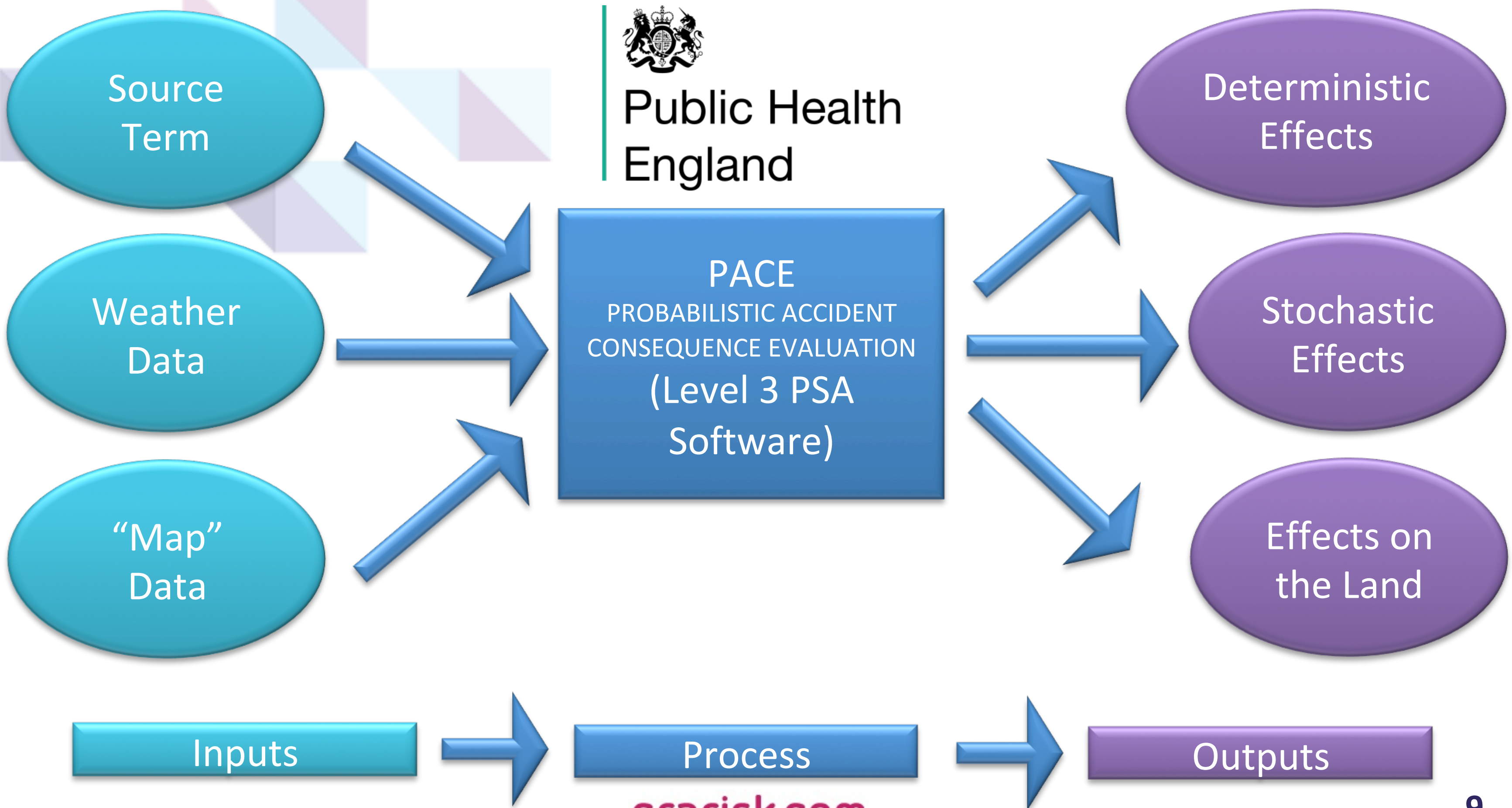
→

**Level 3**
Off-site consequences

## Level 3 PSA

- Helpful to communicate risk in terms of consequences to the public
- Provides an estimate of the residual risk that can't be reduced further
- Informs the optimization of accident management planning, awareness and response to emergency situations with quantified risk measurement.

# L3 PSA software



# The source terms

Source Term

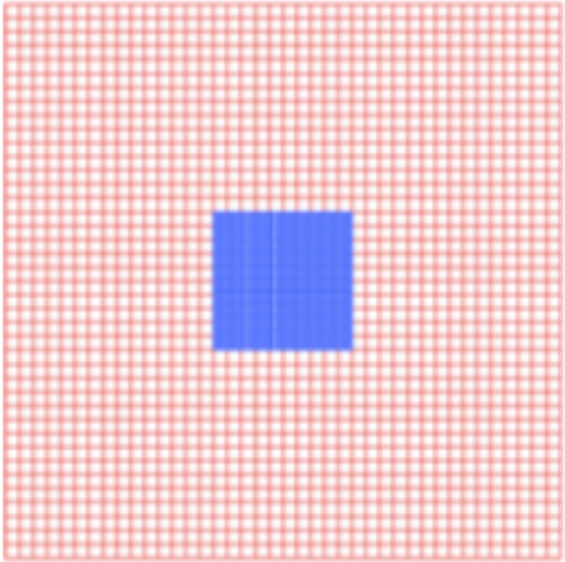
- Source term A – the publicly available EPR source term list for those 2 specific accidents
- The source term was reduced to 30 most relevant radionuclides (and their most relevant daughters)
- Source term B – based on NuScale available core inventory multiplied by the EPR release fraction

## Weather Data

- Parameters like rainfall, wind speed and direction, hours of sunshine, average night and day temperature
- All the weather data was provided by the MET office
- Only data for 1 year, 2011 was used.

“Map”
Data

- The map is the location data
- A square area of 160km×160km was modelled and pre-processed with PACE *Preprocess* tool
- In the square are there are 2 nested grids that define the unit areas of land in which the quantity of interested will be computed. For each grid square population, meat and vegetable production data were added.

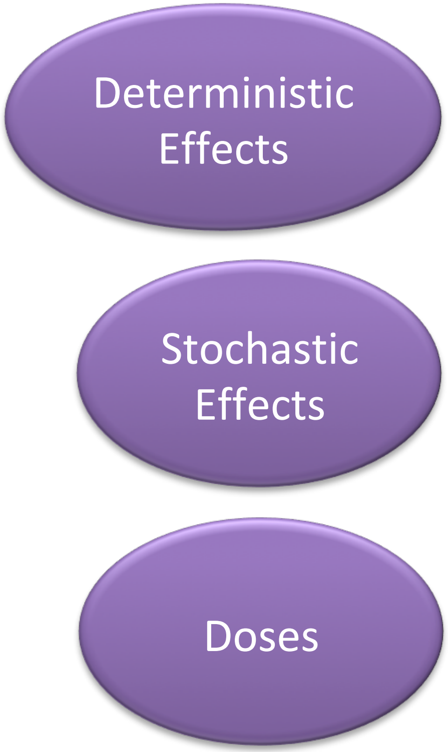


# PACE computational characteristics

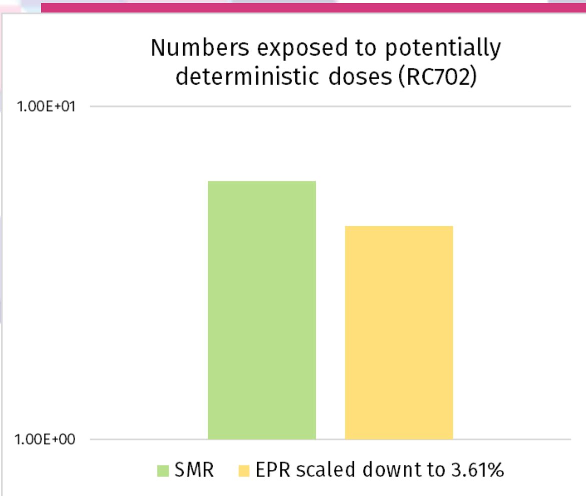
- PACE uses a Lagrangian dispersion model
- With a Gaussian plume model for the dispersion
- It uses release height and duration input data
- PACE also uses a set of time related parameters, including:
- Duration of the release
- Duration of the dispersion
- Number of release cycles
- Time period for integration of the doses to population

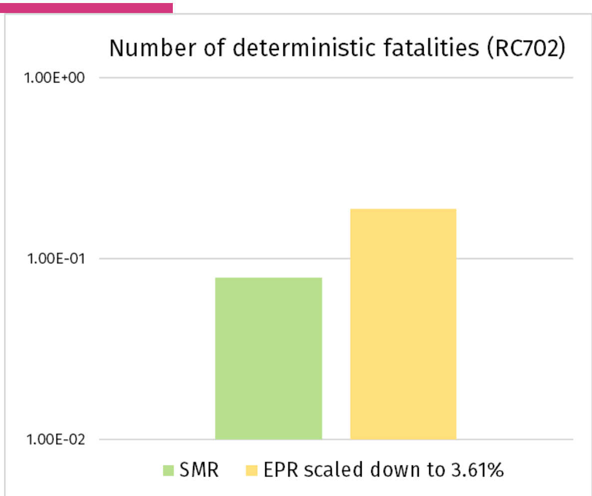
# Results

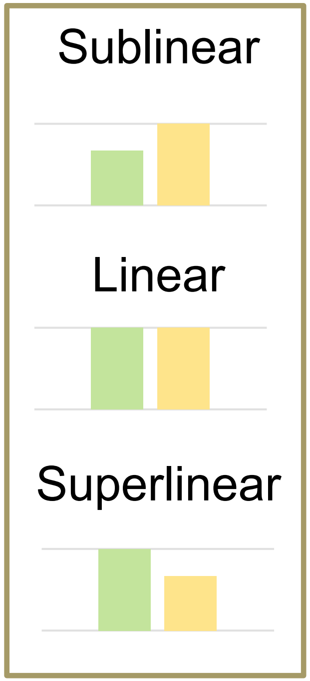
- PACE was used to calculate 3 kinds of endpoints:
- Deterministic: these are related to the damage caused to tissues and organs. There is a threshold effect
- Stochastic: these are related to the potential consequences caused by radioactivity exposure – cancer, cancer in offsprings etc. Linear no threshold model
- Doses and land effects: these are integrated values over time. Code uses 6 pathways for exposure and consider the path of each Lagrangian particle during the integration. 2 time periods used: 1 year and 5 years

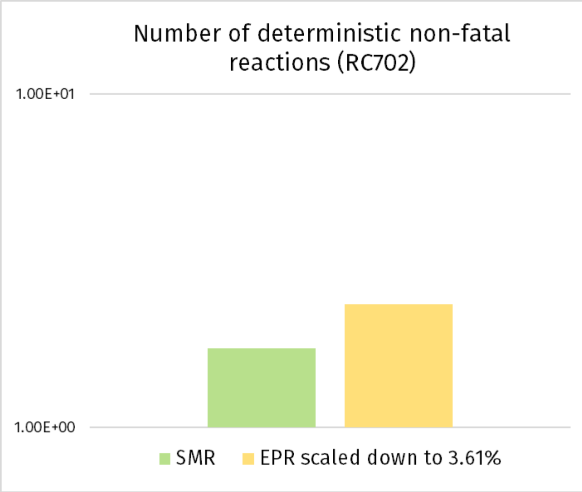


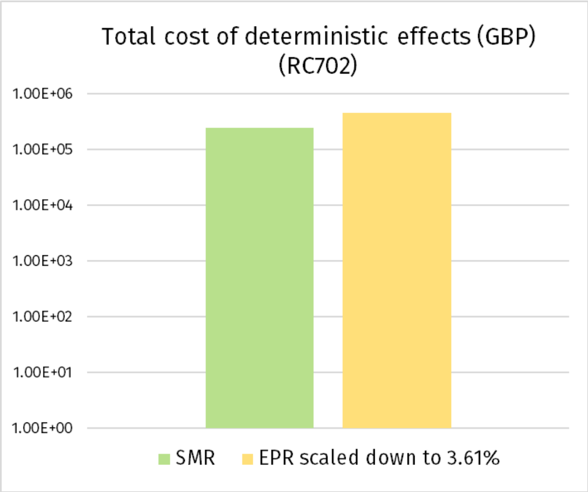
# Deterministic effects



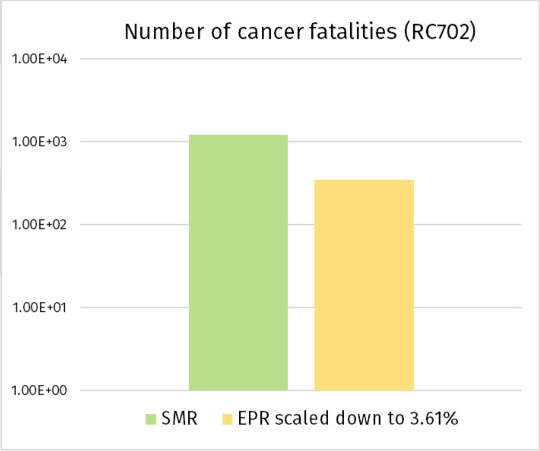



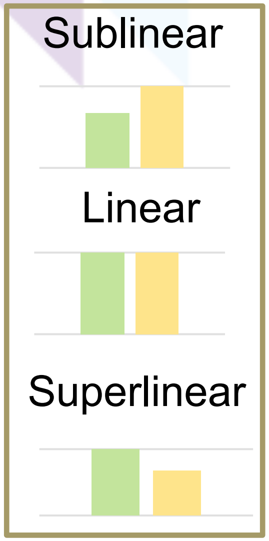



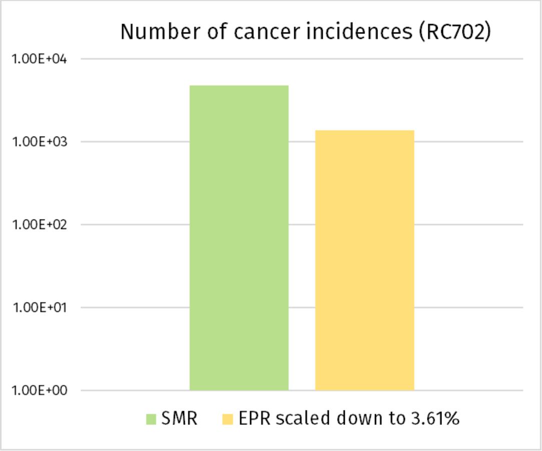



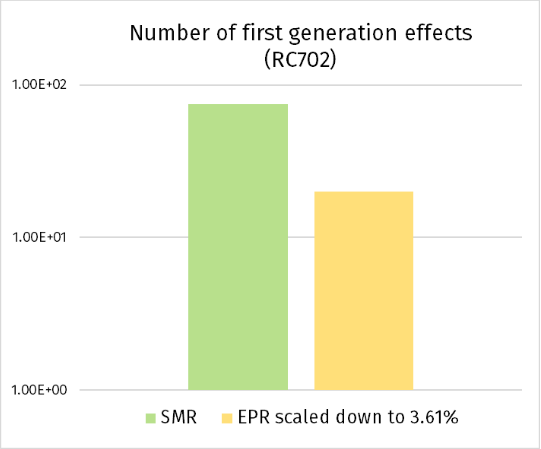



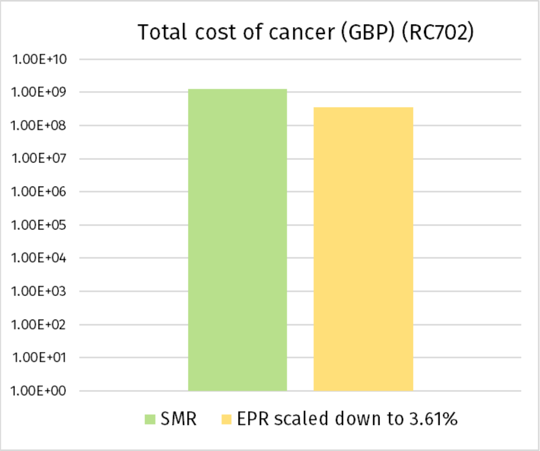
# Stochastic effects

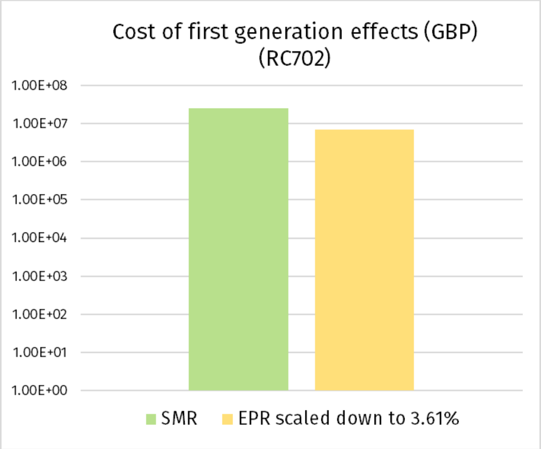


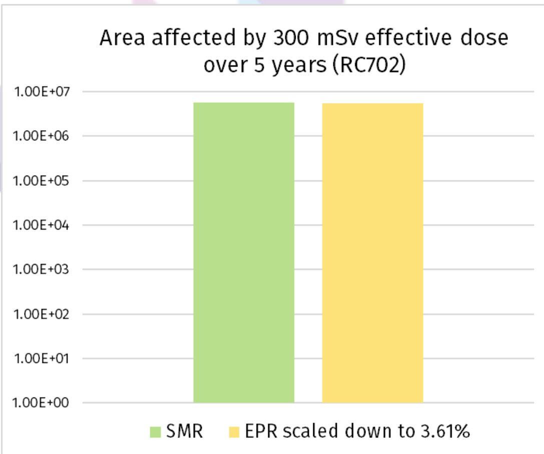



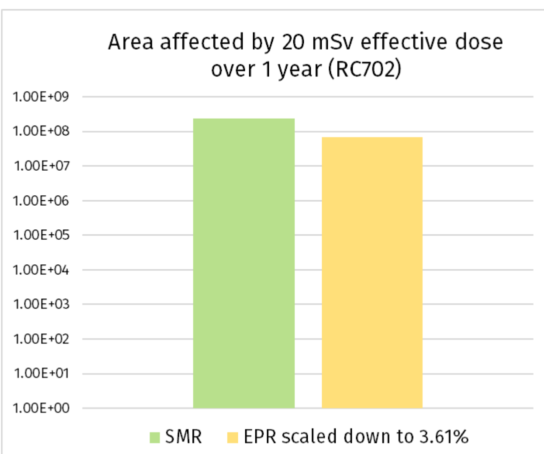



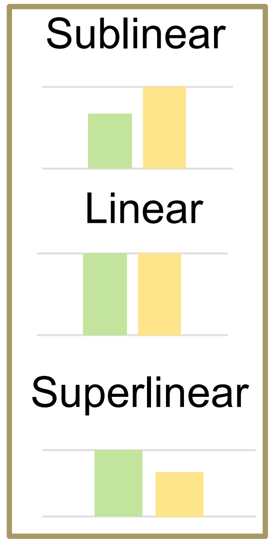



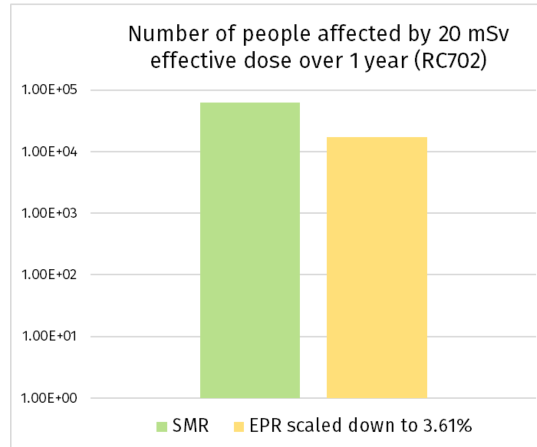



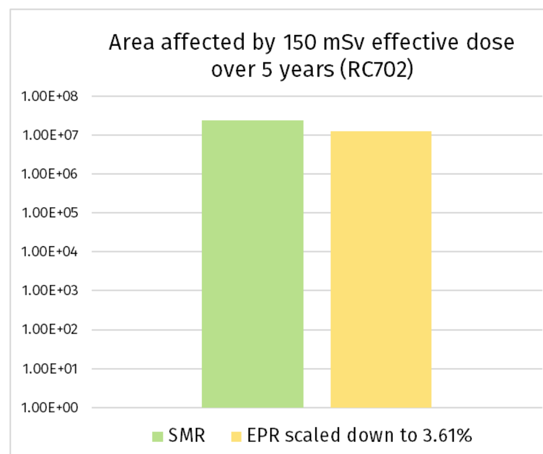
# Doses


Area affected by 300 mSv effective dose over 5 years (RC702)
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
SMR
EPR scaled down to 3.61%


Area affected by 20 mSv effective dose over 1 year (RC702)
1.00E+09
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
SMR
EPR scaled down to 3.61%


Sublinear
Linear
Superlinear


Number of people affected by 20 mSv effective dose over 1 year (RC702)
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
SMR
EPR scaled down to 3.61%


Area affected by 150 mSv effective dose over 5 years (RC702)
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
SMR
EPR scaled down to 3.61%

# Summary of doses and land end points

| | |
|---|---|
| Numbers exposed to potentially deterministic doses | 0.73 |
| Number of deterministic fatalities | 2.42 |
| Number of deterministic non-fatal reactions | 1.35 |
| Total cost of deterministic effects (£) | 1.81 |

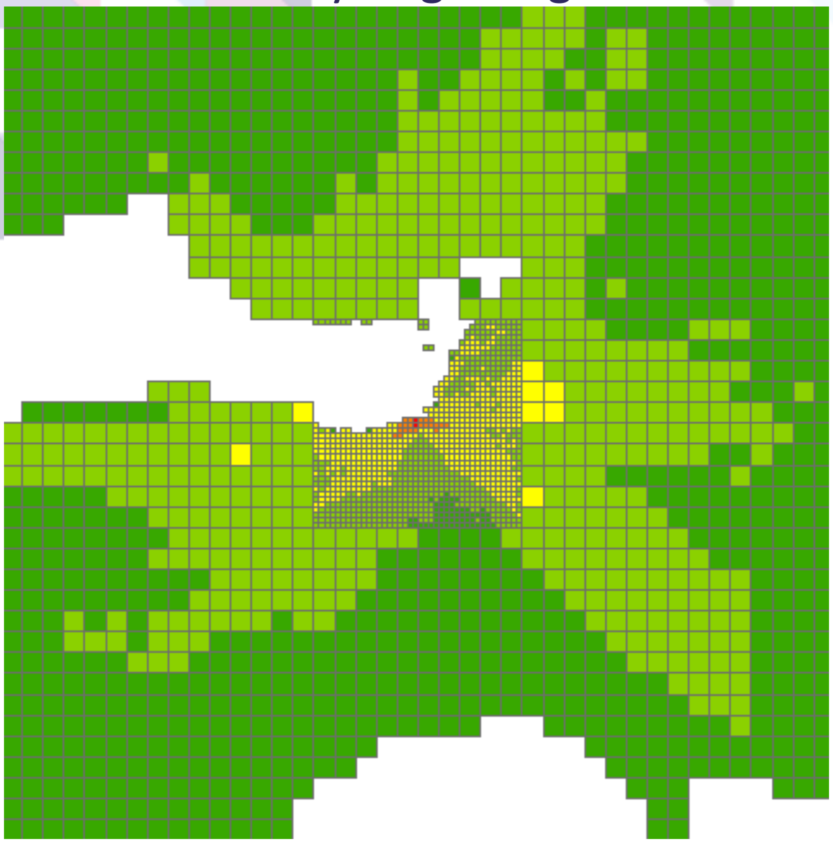
| | |
|---|---|
| Area affected by 20 mSv effective dose over 1 year | 0.30 |
| Number of people affected by 20 mSv effective dose over 1 year | 0.28 |
| Area affected by 150 mSv effective dose over 5 years | 0.35 |
| Number of people affected by 150 mSv effective dose over 5 years | 0.26 |
| Area affected by 300 mSv effective dose over 5 years | 0.96 |
| Number of people affected by 300 mSv effective dose 5 years | 1.59 |

| | |
|---|---|
| Number of cancer fatalities | 0.29 |
| Number of cancer incidences | 0.28 |
| Number of first generation effects | 0.27 |
| Total cost of cancer (£) | 0.29 |
| Cost of first generation effects (£) | 0.27 |

**IF > 1 : greater frequency acceptable for SMRs**
**IF < 1 : greater frequency not acceptable for SMRs**

# Evacuation zone

Probability of getting more than 20 mSv annual effective dose



EPR
2.71 km

SMR
1.38 km

Radius of the area where probability > 30% (**orange**-**red**)

# Evacuation zones comparison

| Accident scenario | RC702 | | RC802aS | |
|---|---|---|---|---|
| **Reactor design** | EPR | SMR | EPR | SMR |
| **Average probability of getting more than 20 mSv per year** | 0.138925 | 0.040618 | 0.145004 | 0.048136 |
| **Area where probability of getting more than 20 mSv per year >30% (km2)** | 23.00 | 6.00 | 21.00 | 6.00 |
| **Equivalent radius (km) >30%** | 2.71 | 1.38 | 2.59 | 1.38 |
| **Area where probability of getting more than 20 mSv per year >20% (km2)** | 672.00 | 24.00 | 770.00 | 27.00 |
| **Equivalent radius (km) >20%** | 14.63 | 2.76 | 15.66 | 2.9 |

# Conclusions

- Depending on the nature of the endpoint considered:
  - the results may result sublinear, mainly for deterministic endpoints,
  - worse than linear, as for stochastic endpoints.
- For potential evacuation zones: the EPR has wider zone as the energy output is higher. Size of the evacuation zone doesn't scale linearly with power. However, it is unclear what would happen with a multi unit SMR site of power equivalent to that of a EPR.
- Further work: sensitivity studies for release duration and release height

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