Case study on the uncertainty and variability in a risk assessment:

Objects on beaches in the vicinity of the Sellafield site

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Aim of the assessment

To estimate the overall risk to health due to the presence of radioactive objects in the environment in the vicinity of the Sellafield site

**Stochastic effects (cancers)**

Estimate the probability that an object will be encountered by an individual within a population of beach users or seafood consumers

Estimate the risk to health to an individual assuming they encounter an object

*Overall risk to health to an individual within a population* = *Probability of encountering an object * risk to health if an object is encountered*

**Deterministic effects (severe tissue damage)**

Assessed the absorbed dose to the colon and the skin
Estimating the probability of encounter

As an encounter with an object is not certain to occur (tens of objects per ha) there is a need to assess the probability that an individual within a population will encounter a random object

Annual probability of encountering an object =
Mass of sand encountered annually via each exposure pathway * Number of objects present per unit mass of sand

Exposure pathways are: skin contact; ingestion; inhalation

Total annual probability of encountering an object is the sum of the probability of encounter for each exposure pathway
Mass of sand encountered

Mass of sand encountered via all exposure pathways depends on:
  • Size of object
  • Age of the individual, what they are doing and for how long

Annual mass of sand in contact with the skin also depends on:
  • Part of body exposed to sand: hands, feet, legs, arms etc
  • Dermal loading: wetness of sand, material of clothing

Annual mass of sand ingested also depends on:
  • Inadvertent ingestion rate (of sand or seafood)

Annual mass of sand inhaled also depends on:
  • Weather conditions (affects resuspension)
Physical size of the objects

Physical characteristics of an object will affect the relevant exposure pathways.

Objects found to date range in size from \(<\ll \text{mm}\) to many cm.

Deliberately picked up: \(> \text{cm}\)
Attaching to the skin: \(\leq \text{mm}\)
Inadvertent ingestion: \(< \text{mm}\)
Ingested by marine animals: \(< 100\text{s }\mu\text{m}\)
Inhalation of suspended material: \(< 10\text{s }\mu\text{m}\)

Sellafield Ltd. report objects in two size classes:

- Particles \(< 2 \text{ mm}\)
- Larger objects \(> 2 \text{ mm}\)

- Cautiously assumed that the probability of encountering any particle is the same and can occur through skin contact, inadvertent ingestion and inhalation.
- Larger objects are deliberately picked up or deliberately ingested.
Beach use - Ideal situation for assessment

- Specific use of an area by a small group of individuals
- Environmental conditions can be defined well
- Habits of those individuals can be defined well
Range of beach types in Cumbria

Affects how people use the area and what they may do

Sandy

Rocky

Pebbles and sand
How people use beaches
Affects the exposure pathway

Playing and digging

Sports

Litter collection

Rock pooling
How people use beaches

Present daily throughout the year
Use the same area of beach

Infrequent visits
Use areas not commonly used
How people use beaches
Reality of how beaches are use

Large range in environmental conditions

• Wet / dry sand, sandy / pebbles / rocky substrate
• Weather (dry / wet, calm / windy, hot / cold)

Large variation in the population of those making use of a beach

• Ages, activities participated in, clothing worn, length and time of visit
Accounting for variability in habits

Assume categories of beach use and define habits for those uses

**Leisure**
- Playing on sand, sunbathing
- Generally in the summer
- Low to middling amount of clothing

**Walking**
- Walking on sand, occasionally picking stuff up (items, pebbles, stones)
- Occurs throughout the year
- Middling to full clothing amount of clothing

**Beach angling**
- Standing on sand and digging for bait
- Occurs throughout the year
- Middling to full clothing amount of clothing
Accounting for variability in habits

Assign distribution to each parameter which covers the potential range in values and how often a particular value is likely to occur

- All pathways make use of a distribution in the annual time spent on the beach

Skin contact
- Area of skin exposed (weather, age, activity)
- Dermal loading (sand wetness, location on body)

Inadvertent ingestion
- Ingestion rate (age)

Inhalation
- Inhalation rate (activity)
- Airborne sand loading (weather)

Seafood consumption
- Mass of sand inside animals, fraction of gut content consumed
Number of objects present
Monitoring programme generates an object find rate
• Number of objects detected per hectare monitored

Probability of detecting an object may not be 100% as it decreases with:
• Decrease in the activity present on an object
• Increasing depth the object is located at due to shielding of overlying sand
  Affected by type of radiation emitted (alpha is harder to detect than beta/gamma)

Object find rate ≠ actual object population per unit area
• Need to account of objects in the environment but not detected
How to estimate the actual particle population

Estimate number of particles present based on those detected using a single detector (as two distinct vehicle mounted systems have been employed)

- All objects detected under the same conditions
  - Detector characteristics, detector speed, detector height

Assume particles are located evenly throughout volume of beach sediment

- Beach morphology review showed regular mixing down to 0.5 m over most beaches

Made assumption that the ratio between find rate and actual particle population is the same for all beaches for each type of particle

*Allows a single factor to be used to scale the find rate to estimate the actual number of particles present per unit area of beach*
Health impact following an encounter with an object

Depends on:

- Radionuclides present on the object
- Activity of each radionuclide present

- Skin contact: dose depends on depth to basal cells (10s to 100s of µm), self absorption by the particle, time the particle is present on the skin
- Dose following ingestion or inhalation depends on how much activity is taken up to the body and which organs/tissues are exposed (eg Am/Pu are taken up by the liver, bone surface and red bone marrow)

- The risk to health per unit dose
- Age of the individual at time of exposure, fatality vs incidence
Examples of variability

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Level of variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time on beach</td>
<td>Few hours to 1000+ hours</td>
</tr>
<tr>
<td>Mass of sand on skin</td>
<td>Few mg to 10s g</td>
</tr>
<tr>
<td>Inadvertent ingestion of sand</td>
<td>Few mg to 100+ g</td>
</tr>
<tr>
<td>Seafood consumption rate</td>
<td>&lt;1 kg to 10s kg</td>
</tr>
<tr>
<td>Activity present on objects (Am or Cs)</td>
<td>Few Bq to 100s kBq</td>
</tr>
<tr>
<td>Detection probability</td>
<td>&lt;&lt;1% to 100%</td>
</tr>
<tr>
<td>Number of objects present</td>
<td>&lt;0.1 per ha to 10s per ha</td>
</tr>
</tbody>
</table>

In summary
- Individually, many parameters can vary by several orders of magnitude
- Cumulative effect of variability (time on beach * number of objects present)
Example of estimated risk

Given that many parameters used in the risk assessment are defined using a distribution, the estimated risk to health is also a distribution.
Example of estimated risk*

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Annual risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5\textsuperscript{th}</td>
<td>1 \times 10^{-13}</td>
</tr>
<tr>
<td>50\textsuperscript{th}</td>
<td>1 \times 10^{-12}</td>
</tr>
<tr>
<td>97.5\textsuperscript{th}</td>
<td>1 \times 10^{-11}</td>
</tr>
</tbody>
</table>

*values presented for illustration purposes

Depending on assumptions made, estimated risks to members of an exposed population can vary by several orders of magnitude.

Due to the way habits are collected, risks apply to a high rate population \textit{not} the general population.

Estimated risks are those faced by a member of the population but not \textit{the} risk faced by a specific individual within that population.
Explaining the risk

Estimated risks are very low and much lower than other risks

<table>
<thead>
<tr>
<th>Probability</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-5} - 10^{-4}$</td>
<td>Annual risk of death from malignant melanoma of the skin</td>
</tr>
<tr>
<td>$10^{-6} - 10^{-5}$</td>
<td>Annual risk of death from all leisure activities in UK coastal waters</td>
</tr>
<tr>
<td></td>
<td>UK tolerable level for risks in the workplace</td>
</tr>
<tr>
<td></td>
<td>Dose criterion for exemption of radioactive waste</td>
</tr>
<tr>
<td>$10^{-7} - 10^{-6}$</td>
<td>Annual risk of death in UK marine waters (summer)</td>
</tr>
<tr>
<td>$10^{-8} - 10^{-7}$</td>
<td>Annual risk of death in UK marine waters (winter)</td>
</tr>
<tr>
<td></td>
<td>Annual risk of death from a dog bite or insect stings</td>
</tr>
<tr>
<td>$10^{-11} - 10^{-13}$</td>
<td>Annual risk of developing fatal cancer from radioactive particles on Cumbrian beaches</td>
</tr>
</tbody>
</table>
Absorbed dose

Absorbed dose to the colon
• 0.03 Gy per particle ingested at the 97.5\textsuperscript{th} percentile
• Assumes continuous contact of the particle with the colon wall
• Threshold dose for effects – 23 Gy
• No chance of serious tissue damage to the colon following ingestion of a particle

Absorbed dose to the skin
• 1.5 Gy per hour from a single particle at the 97.5\textsuperscript{th} percentile
• 0.05 Gy per hour from a single particle at the 50\textsuperscript{th} percentile
• Threshold dose for effects – 2 Gy
• Possible for deterministic effects to occur if a very high activity particle becomes trapped against the skin for several hours (e.g. under a nail)
• For an particle with ‘average’ levels of activity, contact needed for more than 40 hours before effect possible so very unlikely
Accounting for the unknown

Risks were assessed looking at the foreseeable future

How do you account for completely new situations or changes without being overly cautious?

- Possible construction of new facilities
- Climate change (hotter, colder, storms, greater movement of sand)
- Population or individual changes in habits (food consumption rates)

Short term trends

- Short term changes in find rates (averaging areas, averaging timeframes)
Questions