International Max Planck Research School on Earth System Modelling

Simulation of atmospheric krypton-85 transport to assess the detectability of clandestine nuclear reprocessing

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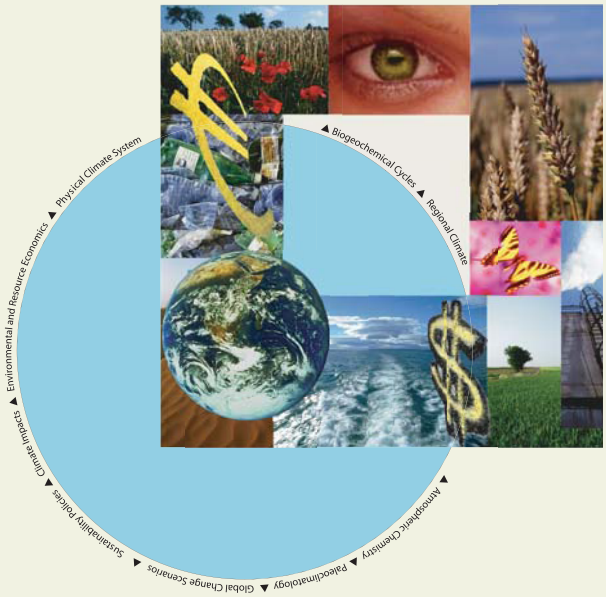

Abstract

The radioactive noble gas krypton-85 is released into the atmosphere during reprocessing of spent nuclear fuel or irradiated breeding targets. This is a necessary step for plutonium separation. Therefore the ^{85}Kr signature of reprocessing could possibly be used for the detection of undeclared nuclear facilities producing nuclear weapon-usable material. The ^{85}Kr content of the atmosphere has grown over the last decades as the emissions from military and civilian nuclear industry could not be compensated by the decay with a half-life of 10.76 years.

In this study, the global ^{85}Kr background distribution due to emissions of known reprocessing facilities for the period from 1971 until 2006 was simulated using the atmospheric general circulation model ECHAM5 applying the newest available annual emission data. The convective tracer transport scheme and the operator splitting for the physical calculations in the model were modified in order to guarantee physically correct results for tracer point sources, in particular non negative concentrations. An on-line routine controlling the ^{85}Kr –budget in the model enforced exact mass conservation. The results of the simulation were evaluated by extensive comparison with measurements performed by the German Federal Office for Radiation Protection with very good agreement at most observation sites except those in the direct vicinity of ^{85}Kr sources. Of particular interest for the ^{85}Kr detection potential was the variability of ^{85}Kr background concentrations which was evaluated for the first time in a global model. In addition, the interhemispheric transport as simulated by ECHAM5 was analyzed using a two-box model providing a mean exchange time of $\tau_{\mathrm{ex}} = 10.5\,\mathrm{months}$. The analysis of τ_{ex} over simulated 35 years indicates that in years with strong South Asian or African Monsoon the interhemispheric transport is faster during the monsoon season. A correlation analysis of interhemispheric transport time with the Southern Oscillation Index and other climate indices over the 35 year period does not show statistically significant correlations.

The potential detectability of emissions from a set of specified source locations was investigated for a hypothetical inspection scenario which allows to take samples close to the concentration maximum of the plumes. For this part of the study, the Lagrangian particle dispersion model HYSPLIT was used. In combination with the location specific background variability derived from ECHAM5, minimum detectable ^{85}Kr releases are calculated depending on the time after release and the distance of the plume center from the hypothetical source location. The results show that the smallest of the ^{85}Kr reference releases, 3.2 TBq, is potentially detectable within 24 hours after stop of release in most cases. The detection probability decreases significantly during the following days. In presence of favorable background conditions as predicted on the Southern Hemisphere, ^{85}Kr plumes stay detectable even about several thousand kilometers from the source location in some cases. These results serve as first benchmark on the capability of using ^{85}Kr for IAEA Safeguards on the Non-Proliferation Treaty and its possible contribution to the verification of a future Fissile Material Cut-off Treaty.