Noble gas nuclides from a BWR

WOSMIP-VIII – Stockholm 2022

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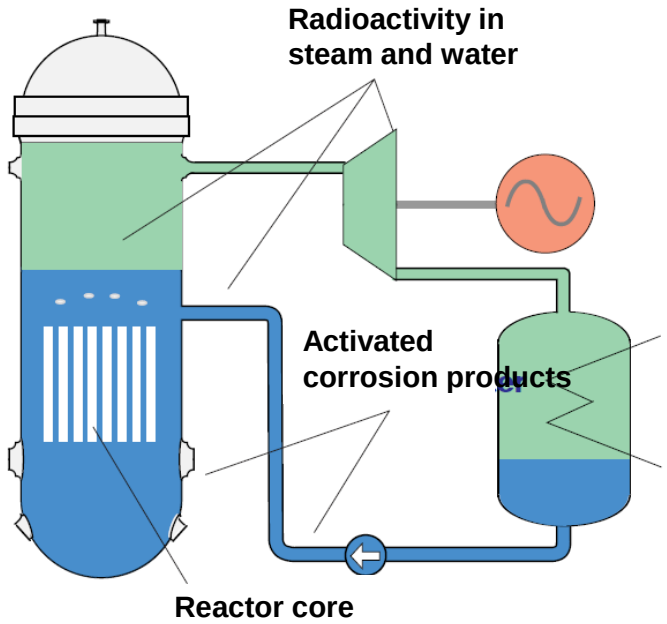
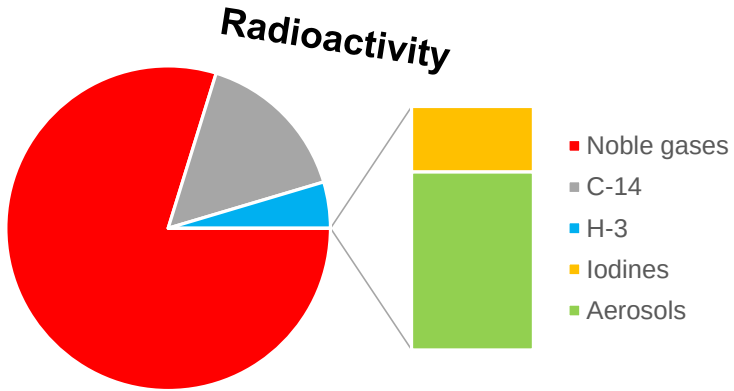
Effluents from a BWR

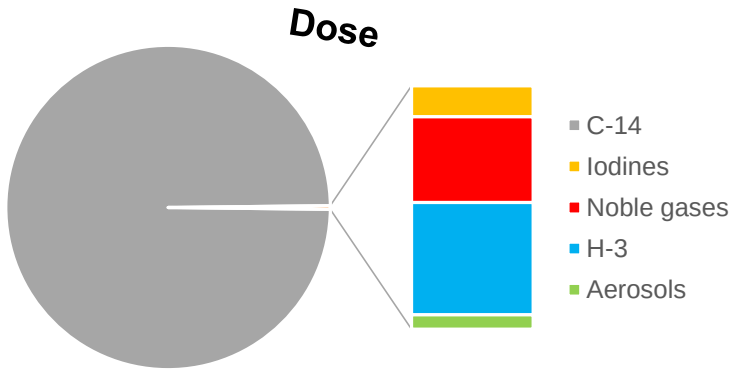
- The BWR has one water/steam loop
- Effluents have in practice three origins
  - Reactor coolant activation (C-14, H-3)
  - Activated corrosion products (Co-60)
  - Fuel: fission products and actinides
- Effluents to air mainly from condenser off-gas evacuation or system leakage
- Effluents to water from discharges of cleaned water not for internal recycling



To air – what is released?

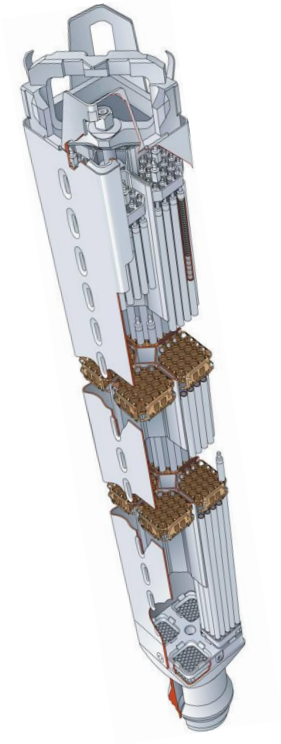
- Most of the radioactivity in effluents to air is rather short-lived noble gases
  - Fission products released from the fuel
  - Non-reactive
  - Low dose impact
- Most of the dose to a representative person near the plant is caused by the effluents of C-14
  - Activation product from oxygen in the reactor water molecules
  - Enters the eco-system
  - Higher dose impact





Inventory – Forsmark 3

- Reactor core:
  - 700 fuel bundles
  - Ca 100 fuel rods per bundle
- Core inventory during operation:
  - 120 000 kg U, 740 kg Xe, 50 kg Kr, 27 kg I etc
  - Noble gas radioactivity according to table
  - ”Gap fraction” is the (very) approximate fraction easily available for release
- Example: Gap fraction Xe-133 in one fuel rod is ca 5E+12 Bq



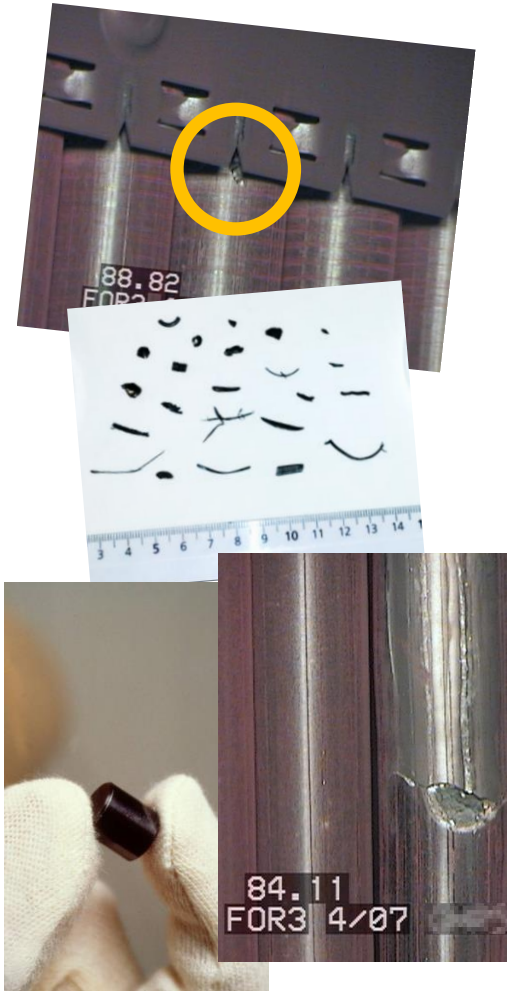
Forsmark 3 - Core Inventory - 3300 MWt

Batch average final burnup 55 MWd/kgU

Nuklid	T½	P [Bq/s] 55 MWd/kgU	I(0) [Bq] 55 MWd/kgU	GapFrac RG 1.183	Gap [Bq] 55 MWd/kgU
Group 2 - Noble gases					
Kr-83m	1.83h	4,3E+13	4,1E+17	5%	2,1E+16
Kr-85	10.72y	5,0E+08	4,9E+16	5%	2,4E+15
Kr-85m	4.48h	3,8E+13	8,8E+17	5%	4,4E+16
Kr-87	1.27h	2,6E+14	1,7E+18	5%	8,7E+16
Kr-88	2.84h	1,6E+14	2,3E+18	5%	1,2E+17
Kr-89	3.19m	1,1E+16	2,9E+18	5%	1,5E+17
Kr-90	32.3s	6,5E+16	3,1E+18	5%	1,5E+17
Kr-91	8.57s	1,8E+17	2,2E+18	5%	1,1E+17
Kr-92	1.85s	4,3E+17	1,2E+18	5%	5,8E+16
Xe-131m	11.9d	2,9E+10	4,3E+16	5%	2,2E+15
Xe-133	5.25d	1,0E+13	6,5E+18	5%	3,3E+17
Xe-133m	2.19d	7,7E+11	2,1E+17	5%	1,0E+16
Xe-135	9.09h	1,4E+14	1,9E+18	5%	9,4E+16
Xe-135m	15.65m	1,0E+15	1,4E+18	5%	7,0E+16
Xe-137	3.82m	1,8E+16	6,1E+18	5%	3,0E+17
Xe-138	14.17m	4,7E+15	5,8E+18	5%	2,9E+17
Xe-139	39.68s	7,5E+16	4,3E+18	5%	2,2E+17
Xe-140	13.6s	1,5E+17	2,9E+18	5%	1,5E+17
Xe-141	1.72s	4,5E+17	1,1E+18	5%	5,6E+16
Xe-142	1.22s	2,4E+17	4,2E+17	5%	2,1E+16

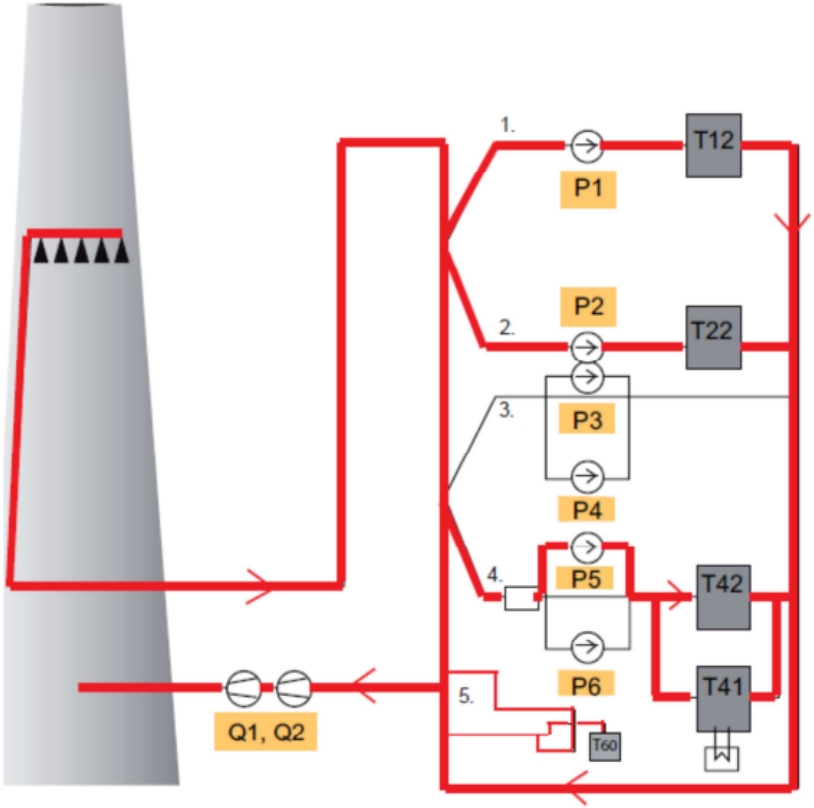
Fuel failures

- Metallic debris may cause mechanical fretting damage to the fuel cladding – a fuel failure
  - First step, release of noble gases
  - Second step, release of soluble fission products
  - Third step, release of fissile material
- Noble gases travel after release: reactor – condenser – off-gas system with delay – <u>main stack effluent</u>
- Fissile material from severe fuel failures will contaminate the fuel cladding for some time
  - Continuous release of noble gases
  - In practice the consequence that decides stop and removal, due to production of alpha active actinides



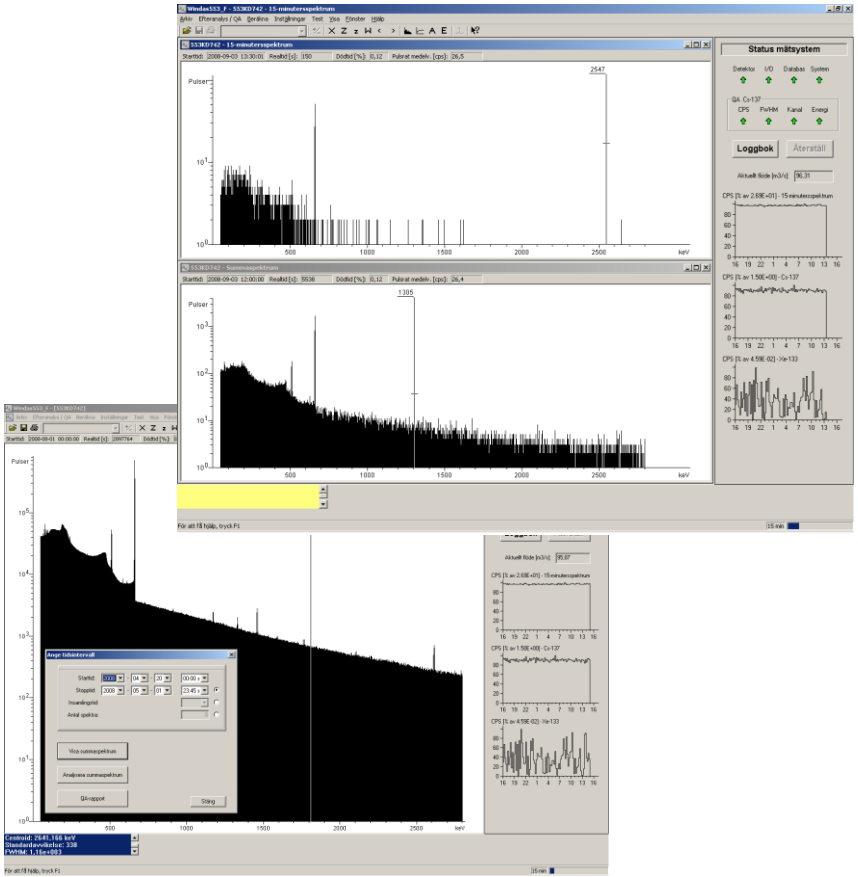
Stack monitoring

- Stack air withdrawn to five sampling lines for direct measurement or integrated sampling of effluent fractions
- Line 4 has two HPGe for continuous direct measurement of noble gases
  - 10 L flow-through Marinelli geometry
  - Ortec GEM15 detectors
  - LN_2 or Ortec X-Cooler III cooling
  - DSPEC Jr 2.0
  - Windas customized software, relies on Gammavision components



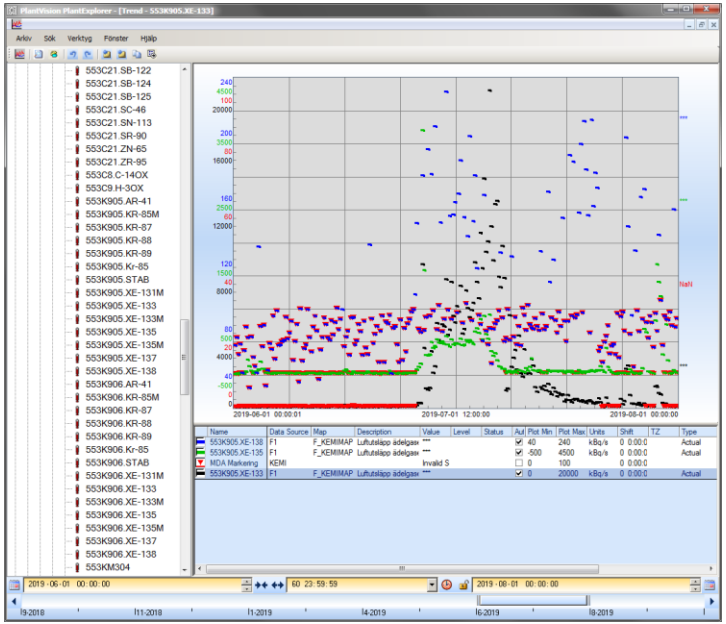
Windas software

- Used for stack monitoring at all three active Swedish NPP sites
- Continuous logging of spectrometry data, time stamps every 15 minutes
- Data reports may be generated automatically or manually
- Manual post-processing allows free choice of time period and time resolution for the results
- Highest time resolution 15 min, useful for detailed study of a specific release



Routine effluent data

- Windas provides noble gas nuclide trends to the Forsmark Process Database, time resolution 6 hours, expressed in kBq/s
  - These data, stack flow and reactor power are exported for STAX since 2020
- Monthly discharges (Bq) for regulatory reporting evaluated from sum spectrum over the entire month
  - Stabilized spectrum is advantageous
- Library nuclides: Ar-41, Kr-85m, Kr-87, Kr-88, Kr-89, Xe-131m, Xe-133, Xe-133m, Xe-135, Xe-137, Xe-138, Cs-137 (QA)



Xe-133 long term effluent trend

- Note logarithmic scale
- Xe-133 effluent varies over orders of magnitude
  - Fuel failures
  - Off-gas delay function
- Typical MDA (RG 4.16)
  - 2E+10 Bq, monthly spectrum or 7,6 kBq/s
  - 2E+09 Bq, 6 hour spectrum or 90 kBq/s