Longer, hotter, dirtier
- risks of increasing nuclear fuel burn-up

Lauri Myllyvirta

energy campaigner

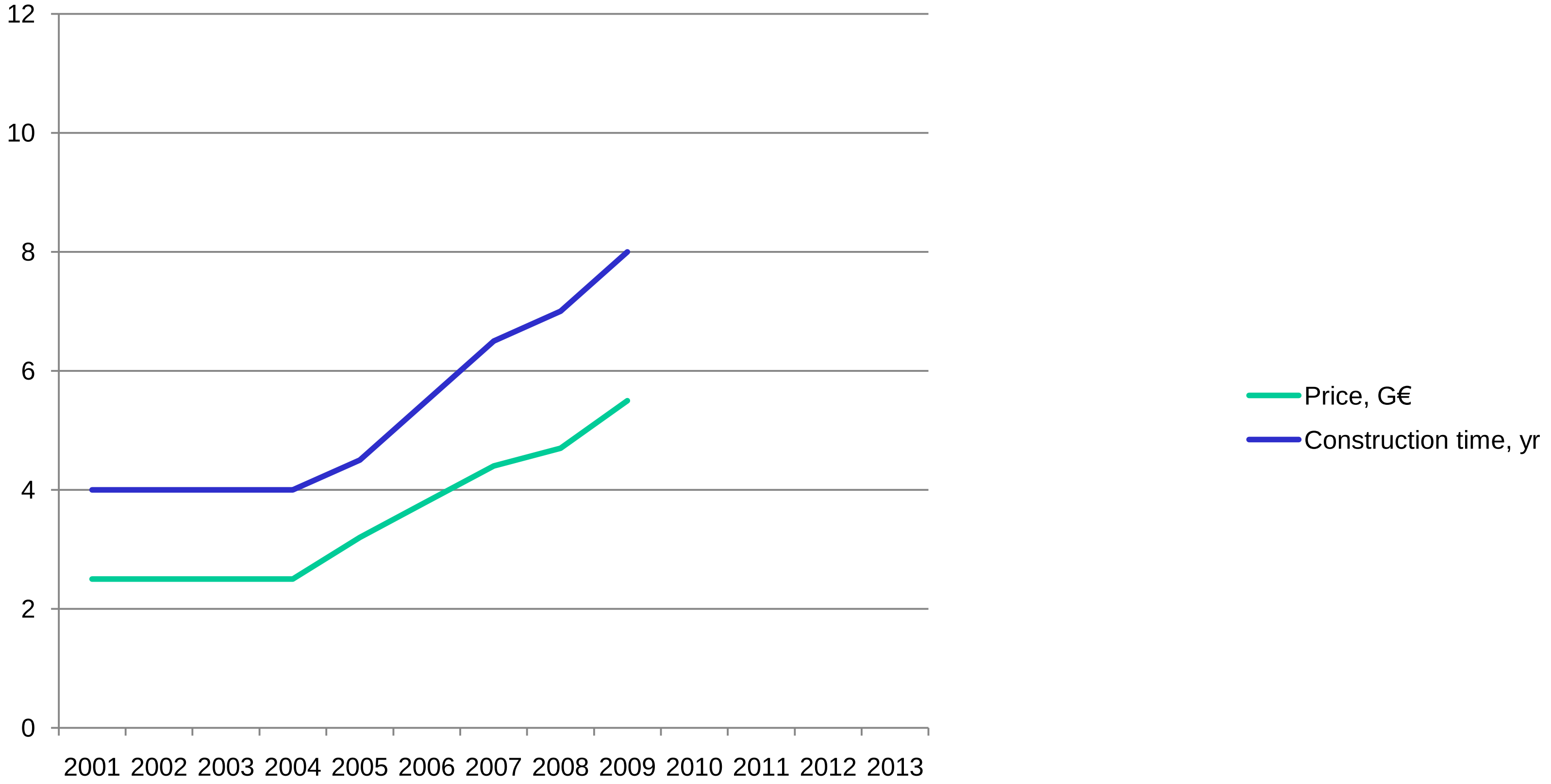
Outline

- Olkiluoto 3
- Burn-up: Short version
- What is burn-up?
- Why increase burn-up?
- How burn-up affects properties of SNF?
- Trends and plans
- What risks are entailed?
- Implications for waste management

Olkiluoto 3: safety failures

- Control&instrumentation – ”nerve center”
  - Design disapproved by Finnish&British watchdogs
    - in Finland high pressure to push on with installation
- Welding oversight: welding procedures not followed, too high current values used which weakens structures

OL3: Price&timetable estimates



Olkiluoto 3: failed promises

- Minimization of risks
- Price&timetable
- Closing down coal-fired power plants
- Jobs
- Reliance on Russia

Burn-up: Short version

- The nuclear industry deliberately designs, modifies and operates reactors in a way that increases health risk by a factor of up to 10, in order to push costs further into the future and onto the society

Burn-up

- Amount of thermal energy released from tonne of uranium in nuclear fuel before removal from reactor
  - GWd/tU, MWd/kgU

Increasing burn-up

- Longer operating cycle
- Higher reactor power (wrt. fuel inventory)
- Higher enrichment ratio (wt-% of U-235)

How burn-up affects properties of SNF

- Higher radioactivity
- Higher heat output
- Increased risk of mechanical failure
  - Increased embrittlement, deformation, more gaseous fission products
- Larger amount of neutron-absorbing substances (actinides), decreased reactivity

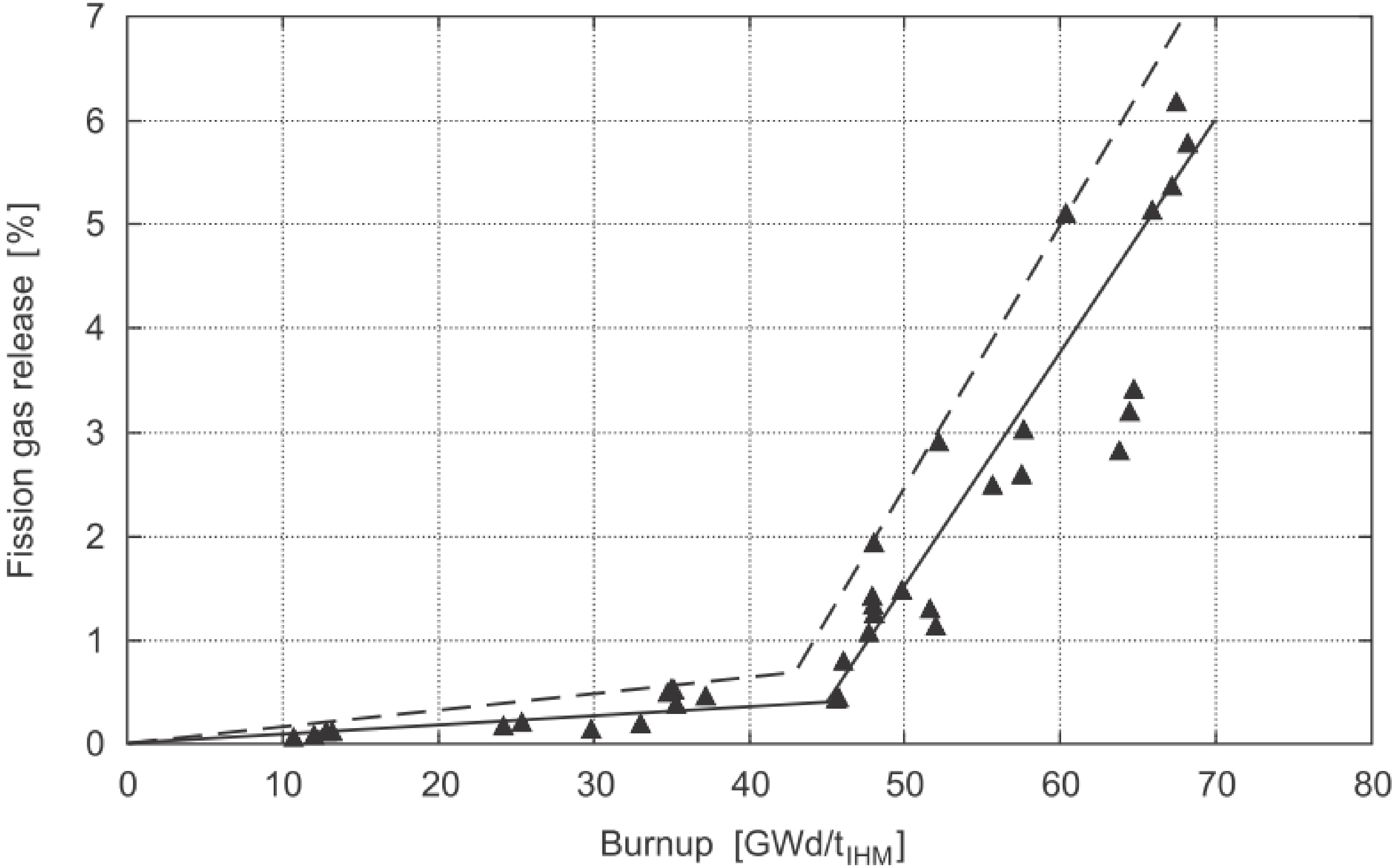


Fig. 3-2: Fission gas release as a function of burnup for French PWR fuel

Instant release fraction

- Higher burn-up
  - increases porosity and decreases grain size of fuel pellets, especially rim region
  - causes build-up and release of fission gas in grain boundaries
- A step increase in these effects occurs around current levels (40-50 MWd/kg)

Instant release fraction

- Radioactive substances are released significantly more easily from SNF upon contact with water when burn-up is increased from 40 to 70 MWd/kg
- Amount of immediately released I-129 increases 10-14 fold in mass terms, 5-8 fold per energy produced
  - I-129 dominates exposure from underground disposal
- Instantly released Cs-135, Cs-137 increase 20-28-fold in mass terms, 11-15 per kWh

➔ Overall increase in health risk per unit of energy by an order of magnitude

Nagra (2004): Estimates of the Instant Release Fraction for UO2 and MOX Fuel at t=0.

Why increase burn-up?

Short answer

- Short term cost savings
  - Higher reactor power
  - Longer operating cycles
  - (Slightly) decreased uranium requirements
- Very limited liability for longer term costs and risks

Liberalisation of the energy market in Europe

- Pressured Electricité de France (EDF) to become more competitive
- Resulted in the testing of high burn-up fuel
- European Pressurised water Reactor (EPR) ‘re-engineered’

EdF 'Optimization' study

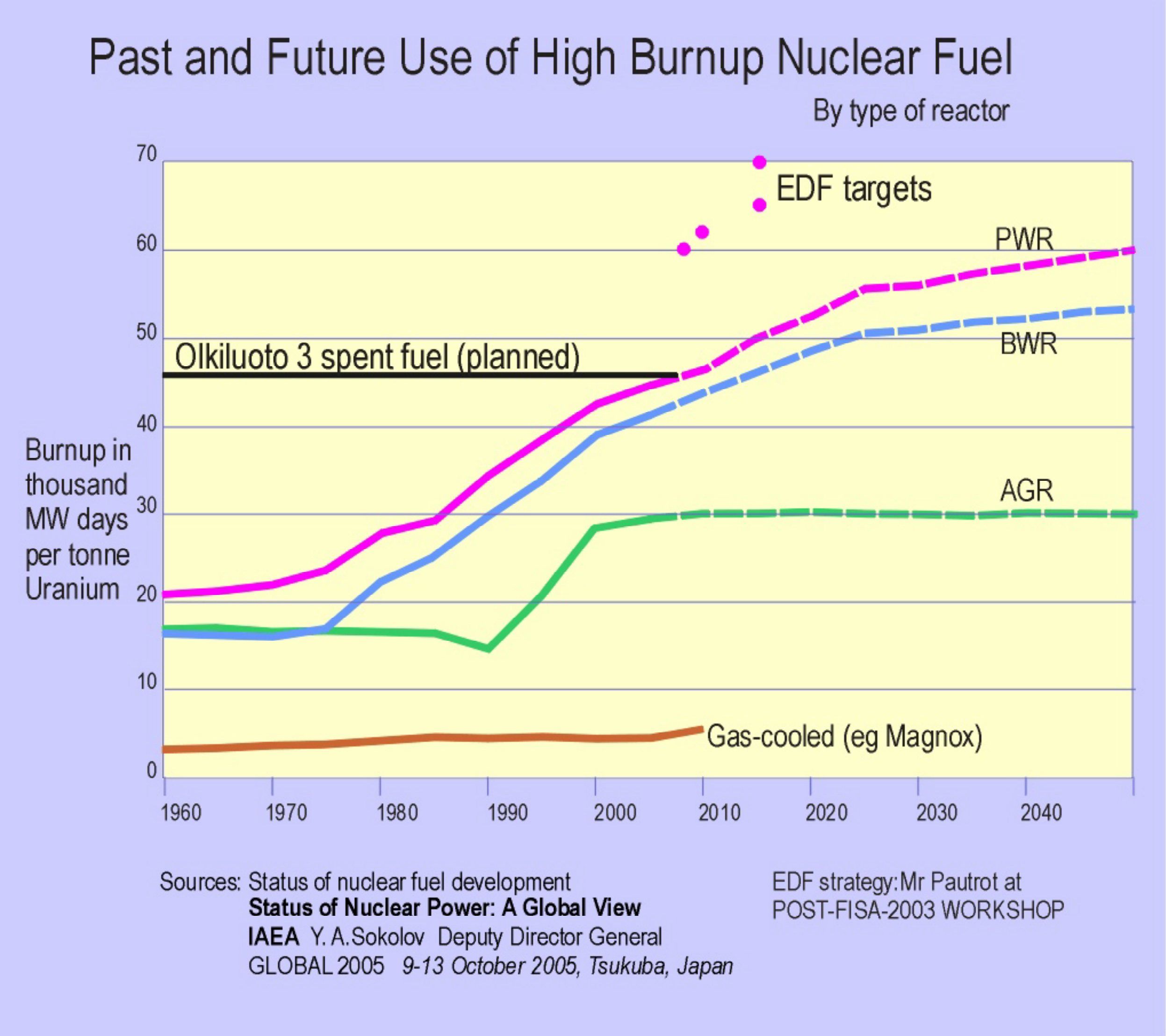
1. 15% increase in the reactor's power
2. Fuel enriched to up to 4.9% uranium235
3. Spent fuel discharged at a burn-up of 60 GWd/tU

- The EdF says that if it cannot use fuel with burn-ups of more than 47 MWd/kg, "nuclear (energy) will have lost its bet" to be a competitive energy source at the beginning of the 21st century.

  Nuclear Fuel No. 26, December 16, 1996, p.12

Dubious cost savings: burn-up credit

- Higher build-up of minor actinides ➔ lower reactivity
- Used as a basis for looser subcriticality standards ➔ Denser packing of fuel
  - Less storage space, less transports
- BUT: even higher heat output, tighter safety margins, higher potential releases



Even higher targets presented in OECD/NEA 2009: Nuclear Fuel Cycle Transition Scenario Studies. Status Report.

IAEA-TECDOC-1433: Remote technology applications in spent fuel management, 2005

- ‘General burn-up trend is heading up to a still higher level, even though there should be a plateau level in confrontation with regulatory constraints’

Olkiluoto 3 burn-up

- Areva: 70+ MWd/kg
- Posiva: up to 70 MWd/kg
- TVO: handling spent fuel not possible in accordance with current regulation (implies substantial increase in burn-up)

Areva (2009): A cost effective reactor. Webpage.

Posiva (2004): Localisation of the SR 97 Process Report.

TVO EIA for OL4 (2008)

Risks throughout the fuel cycle

All stages

- Higher amount of immediately released radioactive substances

Reactor operation: 1990s problems

- Burn-up was increased without due attention to even short-term impacts on integrity of fuel rods
- Deformed fuel rods caused control rods to stick and hindered flow of cooling water
- Also some problems with control rod corrosion
- Imminent problems were quickly addressed through new materials and designs BUT…

FIAEA-TECDOC-1523 : Optimization Strategies for Cask Design and Container Loading in Long Term Spent Fuel Storage, 2006

- Fuel cladding capable of staying in the reactor for longer has been designed without regard to the long-term consequences
- ‘Predictions of the long term behaviour of cladding have significant uncertainties’

Increased accident risk

- Failure of cladding more likely in accidents, especially reactivity accidents: higher demands on emergency cooling
- Higher decay heat: emergency cooling less likely to succeed

Increased accident risk

- “Fission gas effects” represent “a new explosive loading mechanism which may lead to clad rupture under RIA* conditions.“

  *reactivity-initiated accident
- *SCHMITZ F. & PAPIN J. (1999). High burnup effects on fuel behaviour under accident conditions. Journal of nuclear materials vol. 270, pp. 55-64*.

Impacts of an accident

- Higher burn-up means a larger quantity of more radioactive nuclear fuel in the reactor
- A severe accident in the EPR with 65 MWd/kg dischange burn-up would cause double as many cancer cases as largest present-day reactors
- Using MOX fuel would further double the number of fatalities
- The study also presents a feasible accident sequence for the EPR, leading to catastrophic radiological release

Large and Associates 2007: Assessments of the Radiological Consequences of Releases From Existing and proposed ERP/PWR Nuclear Power Plants In France.

Routine emissions

- Drastically higher build-up and release of fission gases means, other things equal, increased routine emissions from reactors.
- Major uncertainties regarding health impacts of routine emissions into air
  - Possible explanation of elevated cancer rates near reactors

Interim storage

- Lower threshold for mechanical failure, higher heat output
- Decades of extra cooling time

2006 US committee on safety of spent fuel storage

- Concluded that the cooling and shielding:

  ‘Could be compromised by a terrorist attack that partially or completely drains the spent fuel pool’

Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report (2006). US Board on Radioactive Waste

IAEA-TECHDOC-1558: *Selection of Away-From-Reactor Facilities for Spent Fuel Storage. A Guidebook*., 2007

- ‘Higher burn-up of fuel has a significant impact on the choice of the storage option and on the design of storage systems, due to the increased decay heat… imposing a higher cooling load to the storage system’

- Present interim storage systems often designed for 25-35 MWd/kg!

Transport

- Higher highly penetrating (gamma and neutron) radiation
- Higher heat output
- Fuel elements mechanically weakened

US Nuclear Regulatory Commission: NUREG-1567 Standard Review Plan for Spent Fuel Dry Storage Facilities, Final Report, 2000

- ‘Limited data to show that the cladding of spent fuel with burn-ups greater than 45,000 MWd/MTU will remain undamaged during the licensing period´
- ‘These burn-up dependent effects could potentially lead to failure of the cladding and dispersal of the fuel during transfer and handling operations’

- “The range of possible and reasonably foreseeable accidents are assessed and some of these are considered to be capable of severely damaging the flask to the extent that a significant radioactive release could occur.”
- After an accident, need for sheltering would “extend out to 30 to 70km and evacuation would have to be undertaken out to about 6km.”

Large and Associates 2006: Risks and Hazards Arising in the Transportation of Irradiated Fuel and Nuclear Fuel Materials in the United Kingdom.

Dry storage

- containment materials and casks are still experimental
- increased emissions, risks and worker exposure from handling

Final disposal

- heat output speeds up the failure of all engineered barriers
- corrosion of copper is very sensitive to temperature
- major uncertainties related to durability of bentonite and biochemistry
- can prevent saturation and/or chemically alter buffer
- increases release and dissolution of fuel
- makes retrieval, already next to impossible, much harder and more dangerous
- increased emissions from capsulation plant

Reprocessing

- Larger amount of fission and activation products causes higher routine emissions and worker exposure
- Radionuclide emissions per tonne of fuel are 2-3 higher in Rokkasho, reprocessing 45-55 GWd/t waste, than La Hague, reprocessing ~30 GWd/t waste.
- Rokkasho to cause a total of 15000 cancer cases globally, from reprocessing fuel from 12 plants.

Fairlie, I. 2008: Estimated Radionuclide Releases and Collective Doses from the Rokkasho Reprocessing Facility.

Implications for waste storage

- higher risks
- increased costs and compounded cost uncertainty
- harder retrieval and cleanup
- increased risk of liabilities to taxpayers
  - especially if the KBS-3 waste dump is found intolerably unsuitable for high burn-up SNF

IAEA-TECDOC-1299: Technical and economic limits to fuel burnup extension, Proceedings of a Technical Committee, San Carlos de Bariloche, Argentina, 2002

- ‘Any benefits of lower electricity costs during the operation of reactors in this way will be offset by an increase in the cost of managing the spent fuel’

Conclusions

- Increased burn-up exposes people to aggravated health and environmental risks from reactor and back-end operations, as well as to huge financial liabilities
- Increased burn-up alone negates any alleged gains in risk level of new nuclear designs
- The short-sighted drive to increase burn-up is evidence of limited liability of the nuclear industry
- Possibility of short term cost decreases and hiking U prices will maintain the incentive to increase burn-up during the lifetime of new reactors

Thank you!

Extra slide: Control&instrumentation

- Lacks hard-wired controls
- Separation of two computer-based systems impossible to demonstrate, safety case based on extremely optimistic assumptions
- Lower-level subsystems can override top-level – like mutiny on a ship