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Title: Robotic Spent Fuel Monitoring – It is time to improve old approaches and old techniques!

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Robotic Spent Fuel Monitoring – It is time to improve old approaches and old techniques!

Increasing the available measurement time by a factor of ~1000
Increasing proximity to the fuel by a factor of ~50

… all while improving the quality of the measured signatures
… reducing the inspection burden on the IAEA
… and providing repetitive, frequent, pin level verification

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Los Alamos NATIONAL LABORATORY EST. 1943

NNSA National Nuclear Security Administration

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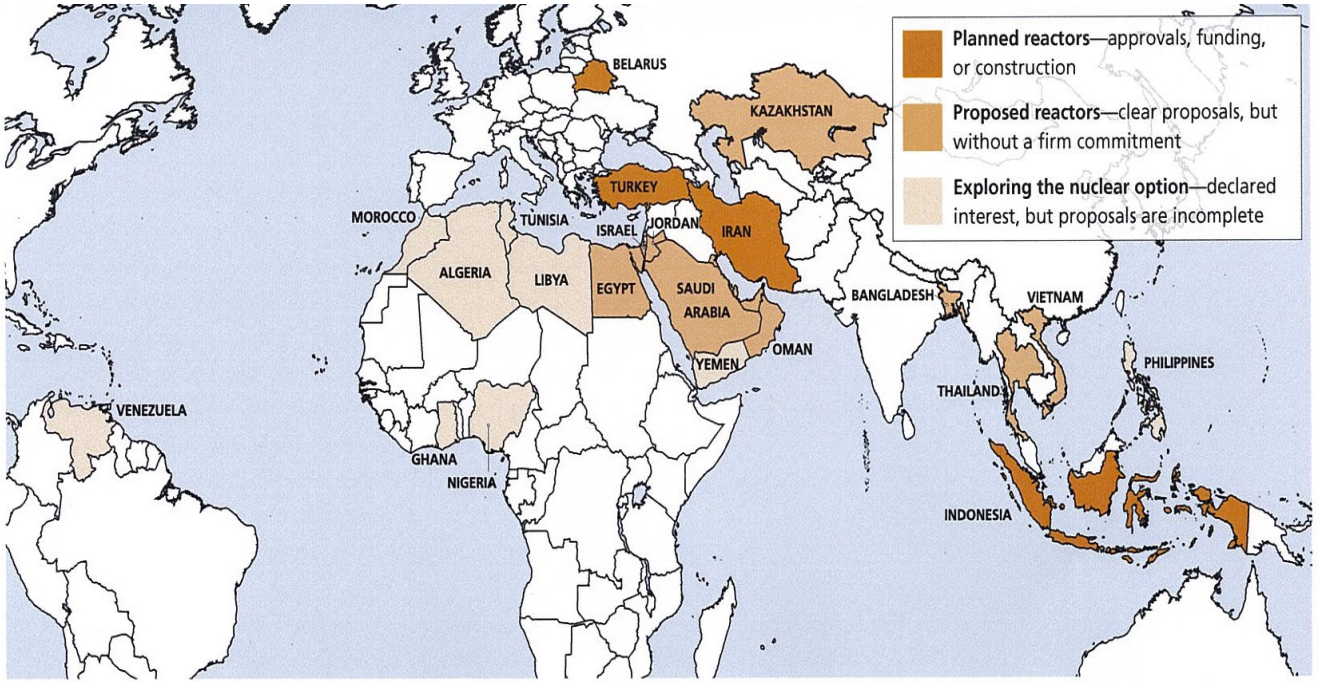
BACKGROUND

State of International Nuclear Development – OECD Projection

It is Time to Prepare for this 21st Century Reality



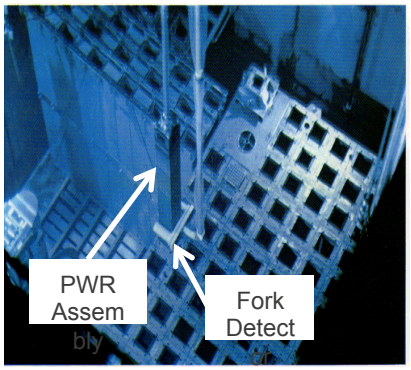
- Nuclear development is spreading to new regions of the world
- Western nuclear firms are expected to be less involved in this new development with Russian and Republic of Korea firms playing a larger role

State-of-the-Practice in International Spent Fuel Safeguards

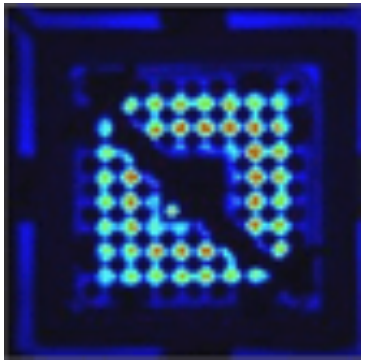
Safeguards is not keeping up with technological change

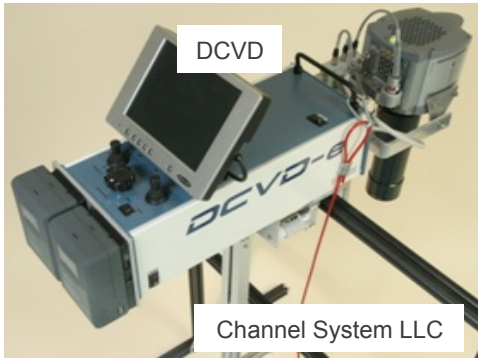
- Present approach …
  - Inspecting once a year to see is 50% of the fuel is present in some fraction of the fuel at the facility
  - Most measurements made by the IAEA are qualitative
  - In general, no effort is made to compare/contrast with past measurements, not data base is maintained to aid future measurement interpretation
  - Continuity of Knowledge (COK) is maintained with cameras located on the facility walls
  - Inspections are human resource intensive
- **Is this acceptable, given modern capability?**

Fork and SMOPY



Cerenkov Viewing Devices (ICVD, DCVD)





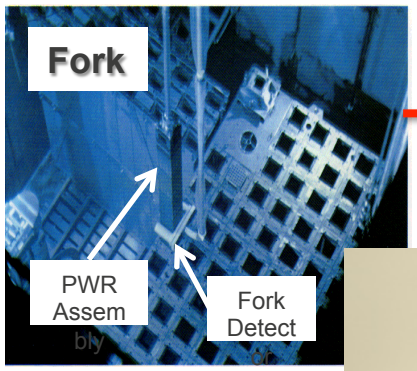
Spent Fuel Attribute Tester

WE CAN DO MUCH BETTER!

IT IS TIME TO CHANGE THE STATE-OF-THE-PRACTICE

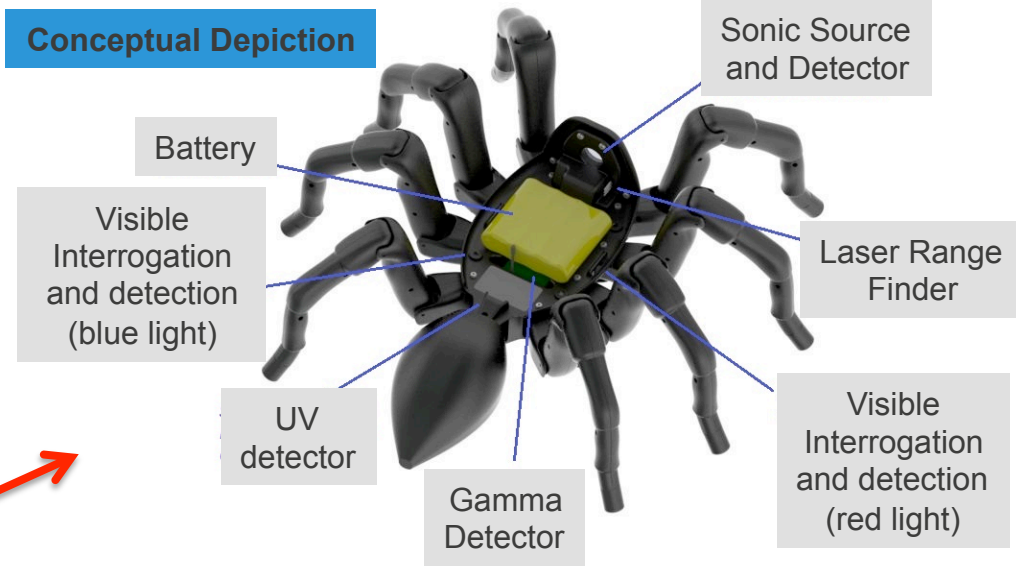
- The IAEA needs tools that reduce the inspection burden while improving the quality of the inspection

- We can achieve "Full Fuel Awareness"
  - A **robotic platform** would allow continuous measurements, not just yearly
  - Expanded suite of measured signatures: sonic, ultraviolet (Cerenkov), visible (multi-spectral), and gamma rays
  - Create measurement data base for comparison in case COK is lost
  - Store data on site and transmit data back to IAEA frequently
  - **Pin-level diversion detection plausible because a robot can be so close to the fuel!**



Cerenkov (ICVD, DCVD)

Conceptual Depiction



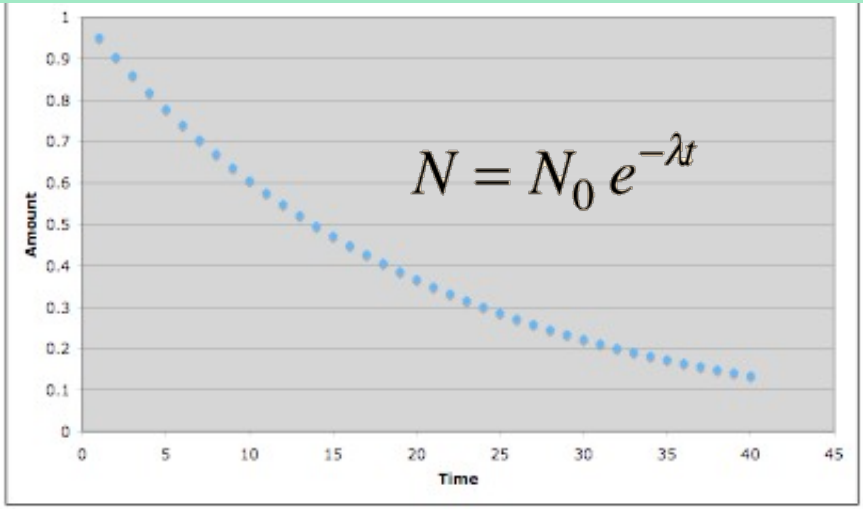
MERIT OF VARIOUS SIGNATURES

GAMMA SPECTRUM

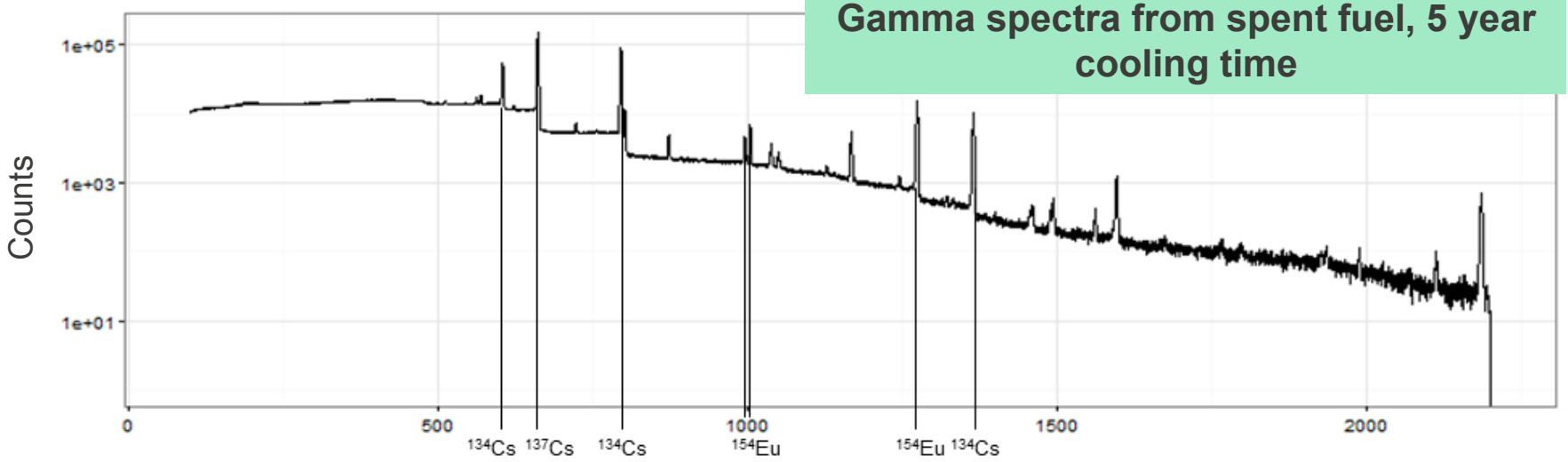
Easy to predict change in gamma spectra as a function of time

- A slow moving robot can measure gamma spectra from the upper most part of every pin
  - Quantified intensity of several peaks from each pin – this could be a fingerprint
  - Given known decay rate of each isotope – we can predict the intensity of peaks of interest on any future date

Exponential Radioactive Decay



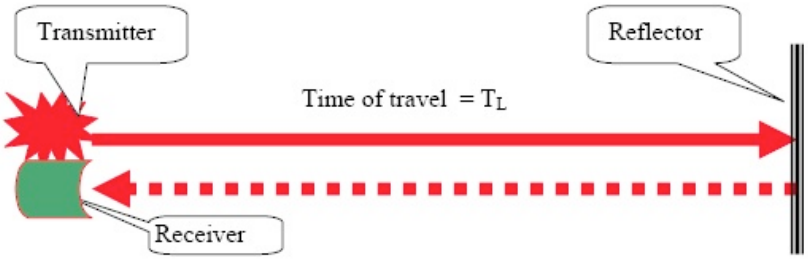
Gamma spectra from spent fuel, 5 year cooling time



VISIBLE SPECTRUM – LASER RANGEFINDER

Addressing the diversion scenario of material in the guide tubes

- Rangefinder technology could be used to verify that each guide tube is empty immediately upon removal from the reactor core … addressing the illicit Pu production scenarios involving insertion of partial length rods into guide tubes.
- Such a measurement is enables by both the close proximity of robotic platform to fuel and vibrational stability of robotic platform

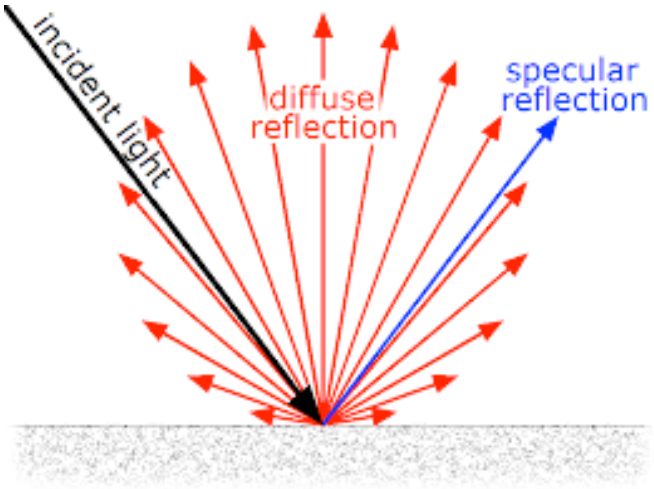


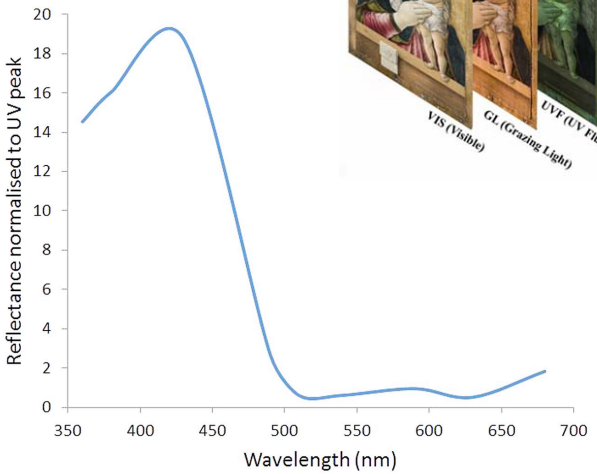
Laser Rangefinder

VISIBLE SPECTRUM (CONT.)

You can see the different between an irradiated assembly and a fresh one

- It is clear to fuel assembly handlers that fresh and irradiated fuel look different. The irradiated fuel looks dull and brownish while the fresh is shinny and metallic
  - Might this observation be useful for diversion detection?
  - Might the optical reflection from the top portion of each pin, perhaps the top 10 cm, provide a unique identifier for that assembly?



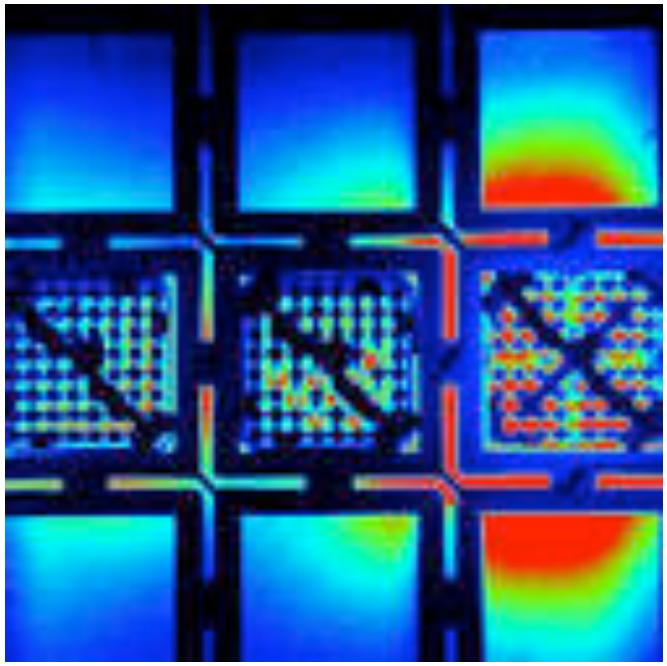


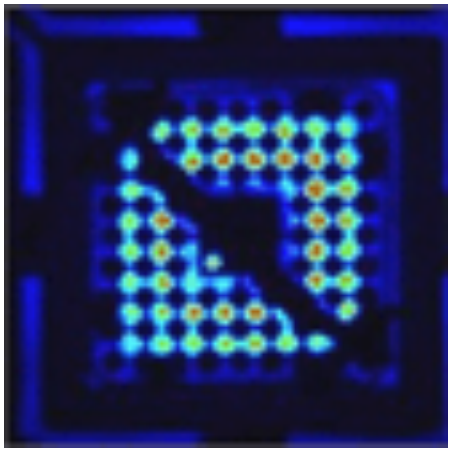
Ultraviolet Spectrum

Essentially a Cerenkov-Viewing-Device with unlimited time & ~50x closer to the fuel

- A slow moving robot can create significantly better images the the current DCVD
  - More time than an inspector who has typically a few minutes per assembly
  - Less attenuation as there would be ~9 meters less water above each fuel assembly
  - Anticipate being able to observe emission from water between all pins by using UV fiber optics

DCVD images – false color



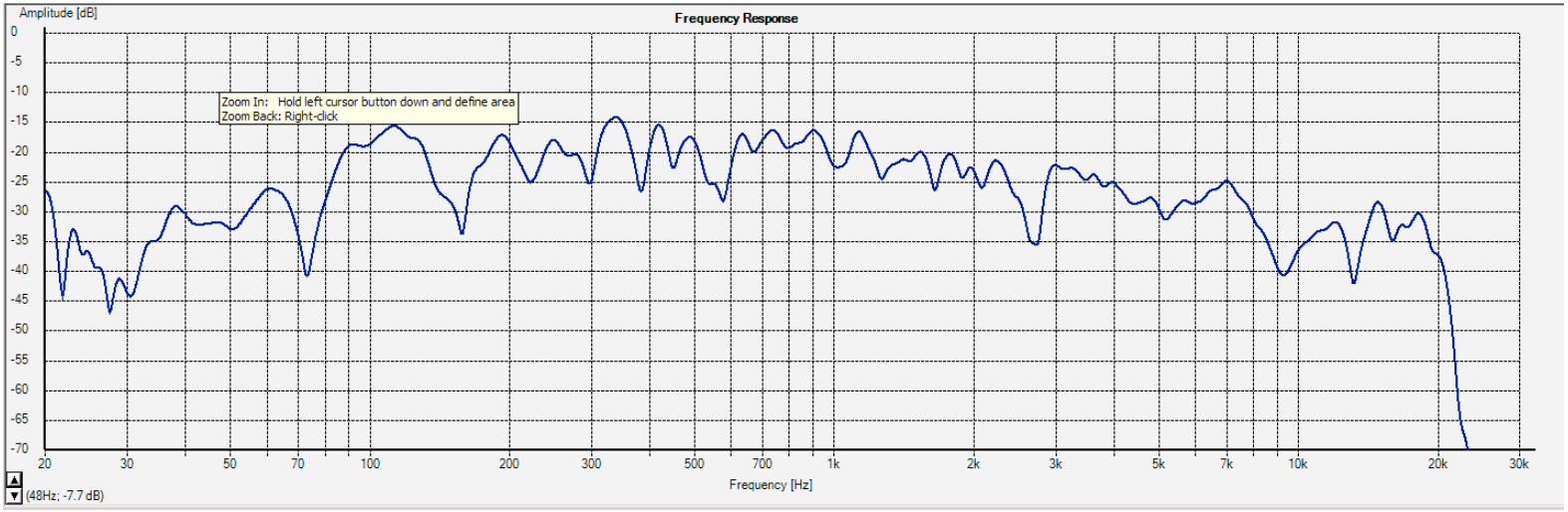


SONIC

Experimental data needed

- Currently anticipate measure of each pin individually to enable pin level diversion detection, speculation of what might be possible:
  - Each pin creates a unique vibrational fingerprint
  - Or, perhaps each pin is not unique but each assembly is given the ~60 to ~300 pins in each assembly
  - Or, pins may fall into classes:
    - Fresh pins containing uranium pellets (pliable metal with loose pellets inside)?
    - Spent pins containing uranium pellets (vibration impacted by swelling of pellets and radiation induced brittleness of cladding)?

Example of vibrational response (amplitude) to a scan in input frequency for a given object



IMPACT ON SAFEGUARDS

SAFEGUARDS WILL BE IMPROVED BECAUSE …

- Currently able to verify that "50% of the fuel is there"
  … We will add **pin-level detection capability**
- Currently **incapable** of detection partial length rods in guide tubes
  … We will add **range finder capability**
- Currently there is **no data base** of signature for each assembly
  … We will add such a database stored on site and sent back to IAEA.
  Resulting in a **immensely improved capability to recover from a loss of COK**
- Currently inspections are performed yearly on a subset of assemblies
  … We will measure **all the assemblies with daily-to-weekly frequency**
- Currently inspections are labor intensive
  … We will **free the inspector to spot check irregularities and outliers**

The above benefits can be achieved with passive gamma and a laser range finder on a robot. The range of NDA options are suggested because the best option is not clear.

CONCLUSION

- **"Full Fuel Awareness"**
  - Robotic deployment enables ~1000 times greater measurement time
  - Instruments ~50 times closer to fuel, this proximity combined with vastly greater measurement time, enabling pin level detection
  - No need for a sampling plan, we will measure all assemblies, with superb spatial resolution, repetitively, while saving the data on-site and/or sending it back to the IAEA.

Backup Slides

Timely Detection of Diversion is a Key Attribute of International Safeguards

"*The **objective of safeguards** is the **timely detection of diversion** of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and **deterrence of such diversion by the risk of early detection***."

IAEA INFCIRC/153

Today's state-of-practice:

- Over reliance on human-intensive technologies