Use of surveillance data in RPV integrity assessment

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Problem definition

- **Reactor pressure vessel (RPV) is a unique component**
- **Nuclear reaction is realized inside RPV = heart of the NPP**
  - Thus, RPV is the most important component of the whole NPP
- **RPV contains all nuclear fissile materials**
  - Their 100 % integrity must be assured
- **RPV practically cannot be replaced**
  - Determined lifetime of the whole NPP

Problem definition

- **Thus, design, manufacturing and operation of reactor pressure vessel must assure that the radioactive content (fuel elements) will not be released to the outer space in all operational regimes and conditions including most severe ones like**
  - Core melting on one side
  - Pressurized thermal shock (PTS), on the other side

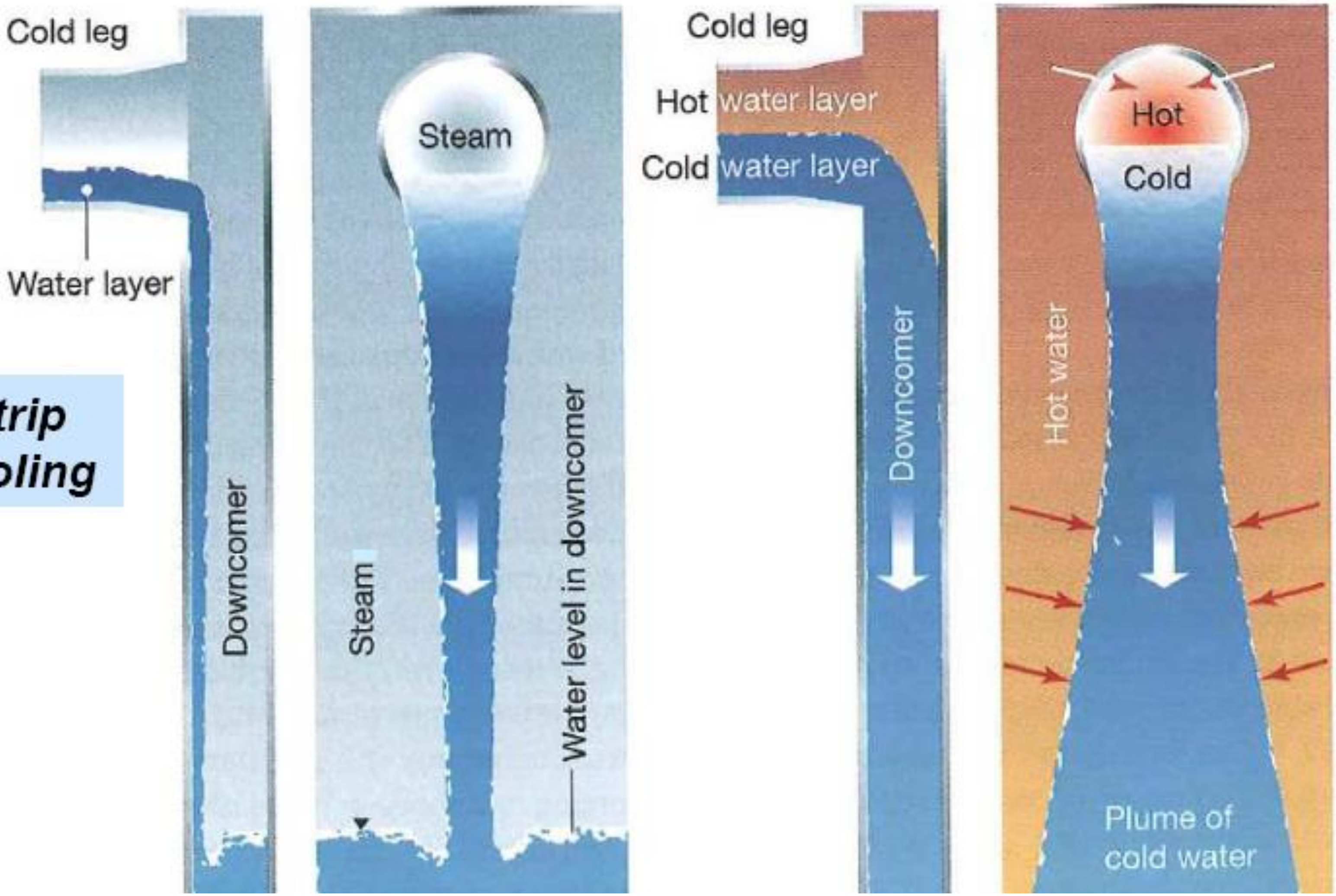
Problem definition

- During situation with core melting, it is necessary to ensure the RPV integrity at high temperatures

- During PTS regimes the RPV integrity must be ensured in relatively low temperatures, in comparison with operation temperatures

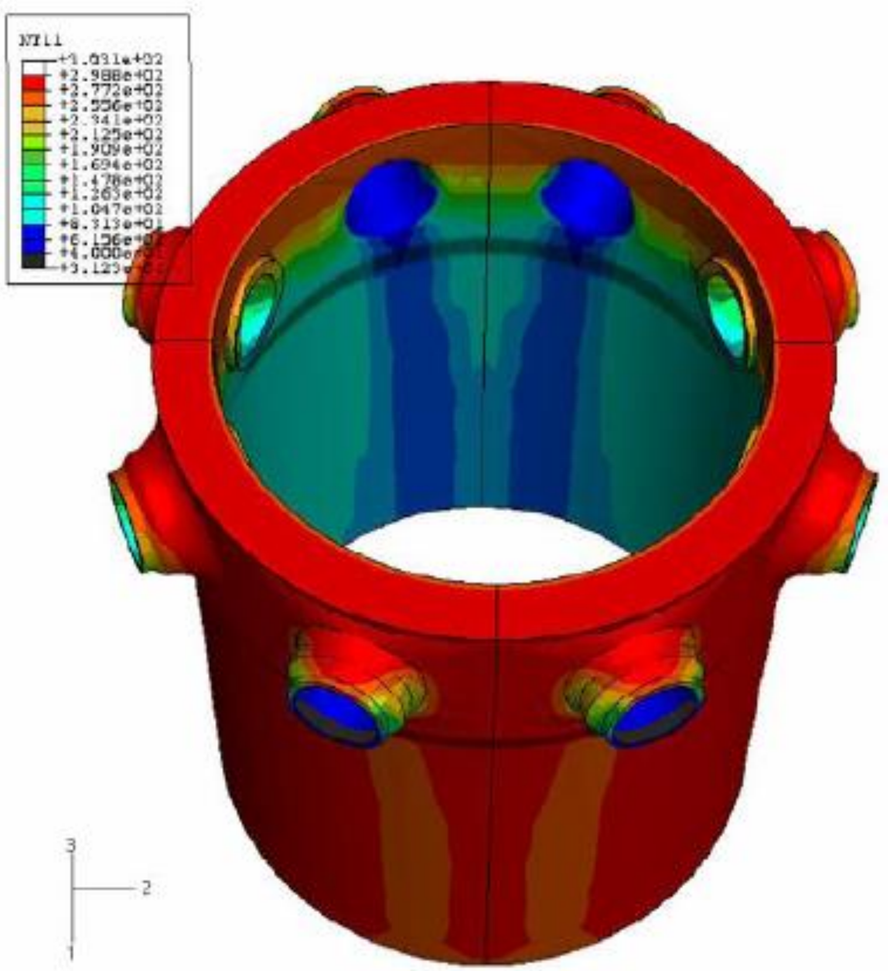
Thermal hydraulics calculation of PTS

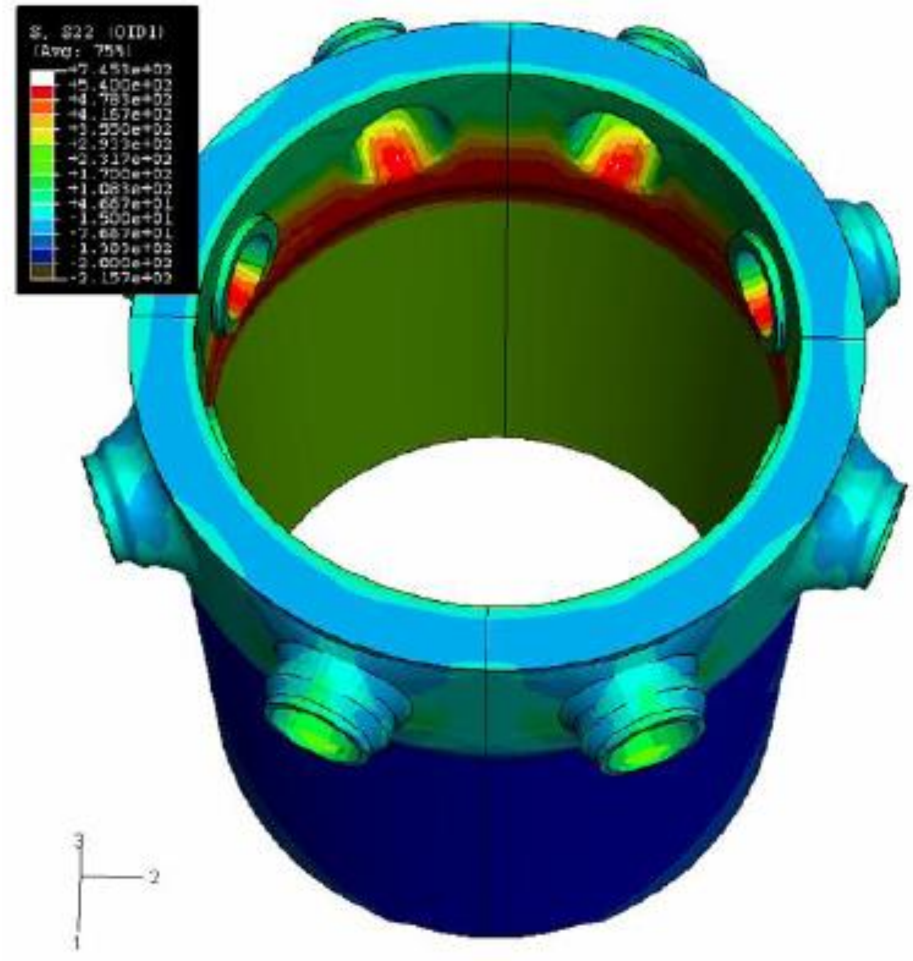
Strip cooling



Plume cooling

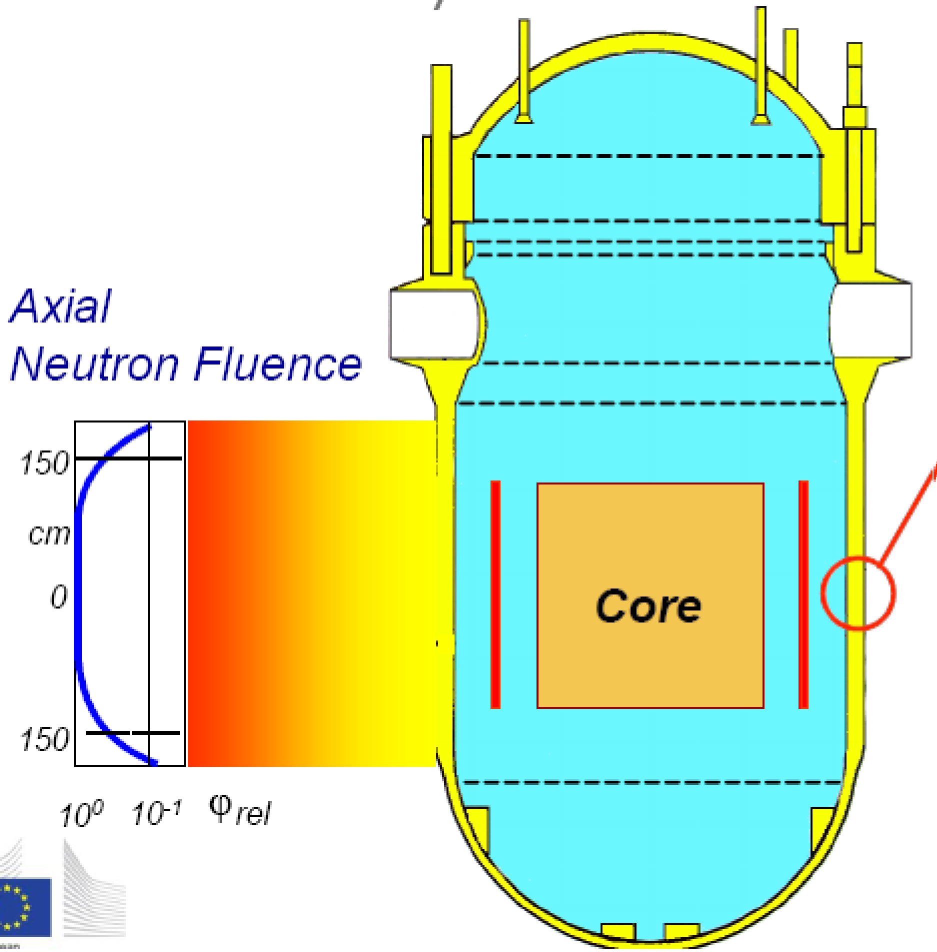
Thermal hydraulics calculation of PTS

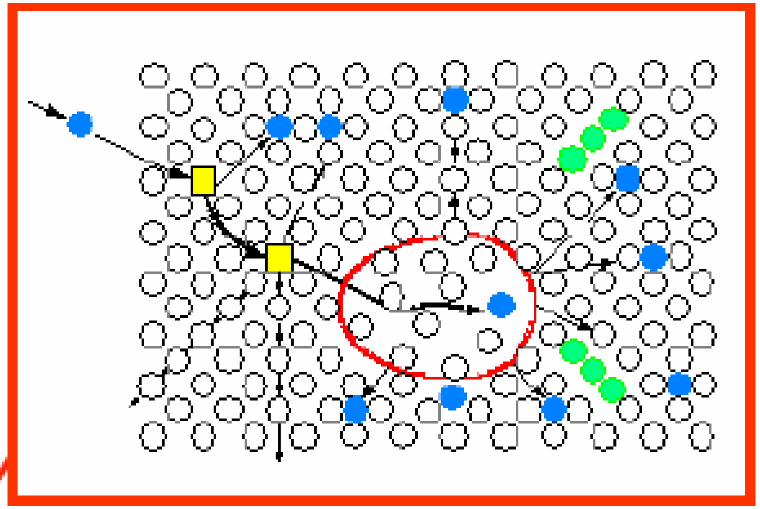




RPV and neutron fluence

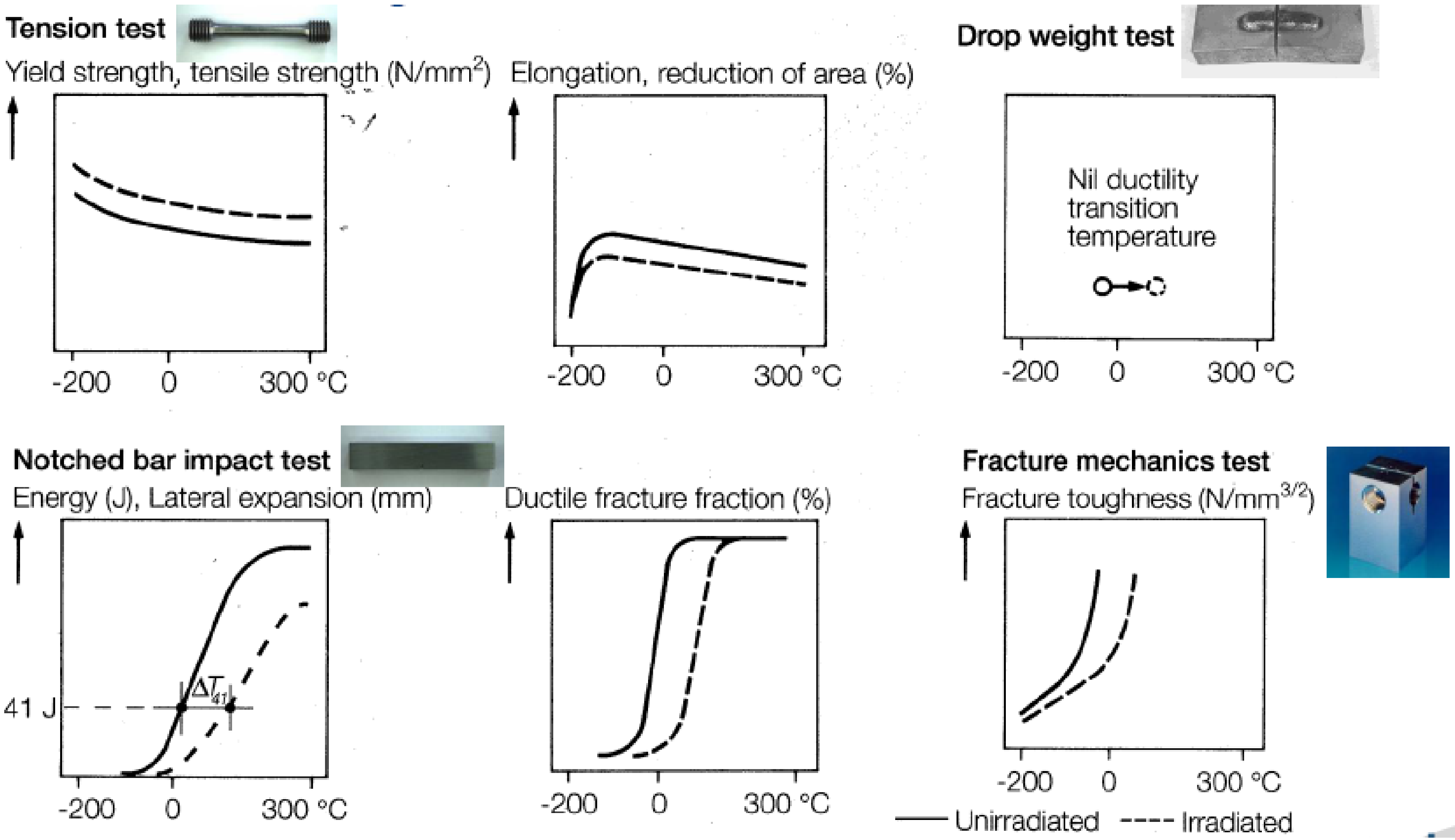
✓Ferritic low alloy steel





- Matrix damage
- Cu-Rich Precipitates (CRP) with Ni, Mn, Si, …
- P segregation on grain boundary

Impact of fast neutron fluence on RPV



Neutron embrittlement

- **Radiation (neutron) embrittlement of RPV materials depends on:**
  - Neutron fluence
  - Irradiation temperature
  - Type of material
  - Contents of detrimental elements like P, S, Cu, As, Sb..
  - Content of alloying elements like Ni, Mn, Cr ..

Neutron embrittlement

- **In most of the codes, prediction formulae for assessment of radiation embrittlement – shift of transition temperature – exist**
  - But they are based on existing database of RPV materials of given standard/type
  - Represents medium trend dependence and upper boundary dependence, usually 95 %
- **But radiation embrittlement is strongly plant specific**
  - As not all material characteristics can be included into such formulae

Neutron embrittlement

- **Use of only plant specific predictive formulae can lead to**
  - Not supported high conservatism that can result in a great reduction of RPV lifetime (or reduction of its operating conditions), on one side
  - Even non-conservatism on the other side when plant specific properties of RPV beltline material properties would have higher sensitivity to radiation damage than the other part of the database – this can be result of some detrimental unknown effect of some parameter not included in the formulae

Surveillance specimen programmes

- These two possibilities are the main reason for „RPV surveillance specimen programmes“ that are implemented into the RPV to monitor changes of materials properties of a given RPV
- These programmes should contain all critical materials from the RPV most irradiated-beltline region, like base metal, weld metals and heat effects zone (HAZ) of beltline rings
- But also materials from austenitic cladding (even though it is not required by all codes)

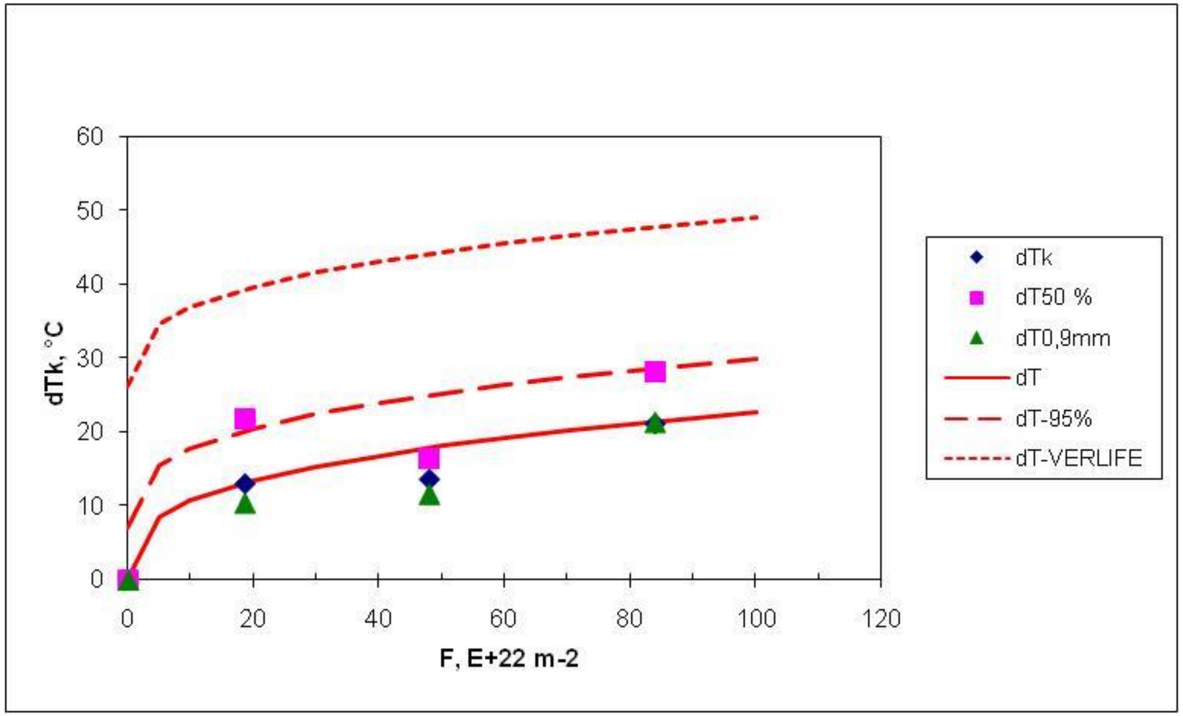
Surveillance specimen programmes

- Surveillance programmes usually contain only tensile specimens and Charpy V-notch specimens for impact tests but for the the direct application of fracture mechanics material properties into RPV integrity calculations specimens for static fracture toughness tests shall be also included
- All these standard and additional requirements are fulfilled in surveillance programmes in the Czech NPPs – Dukovany and Temelin

Surveillance test results

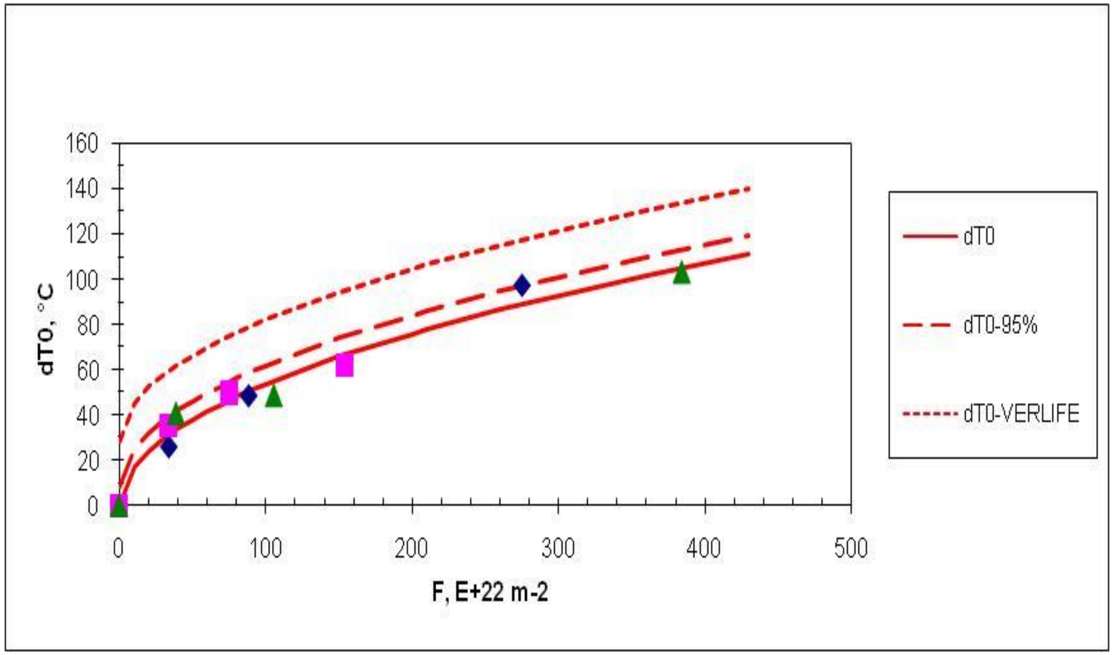
- **Practically only one official code contains requirements and procedure for evaluation of results from surveillance specimens tests including the application to RPV integrity assessment**
  - VERLIFE – IAEA guidelines assessment of integrity and lifetime of components and piping in WWER type NPPs during operation
- **This document prefers results from static fracture toughness tests, i.e. determination of transition temperature T_0 according to „Master curve“ approach against standard brittle fracture transition temperature T_K using charpy-impact specimens.**

Examples of evaluation



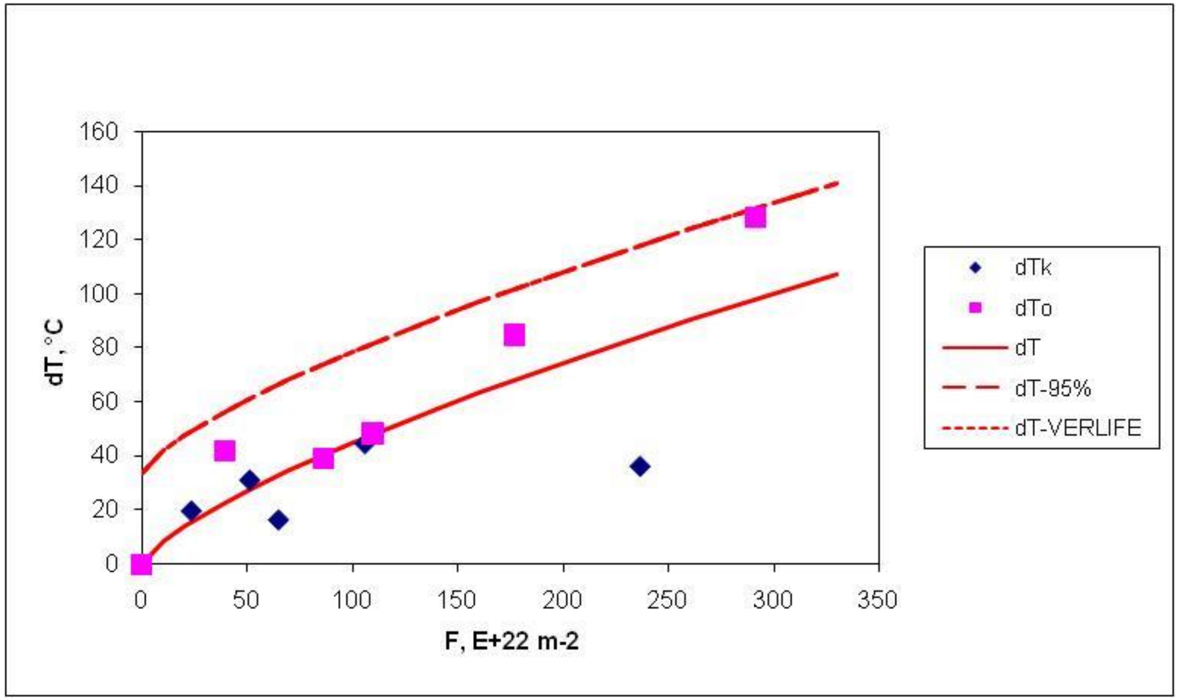
- The example of evaluation shows that these plant specific data are much lower than the predictive formulae given by the code and thus a non-supported conservatism would be inserted into the RPV lifetime evaluation

Examples of evaluation



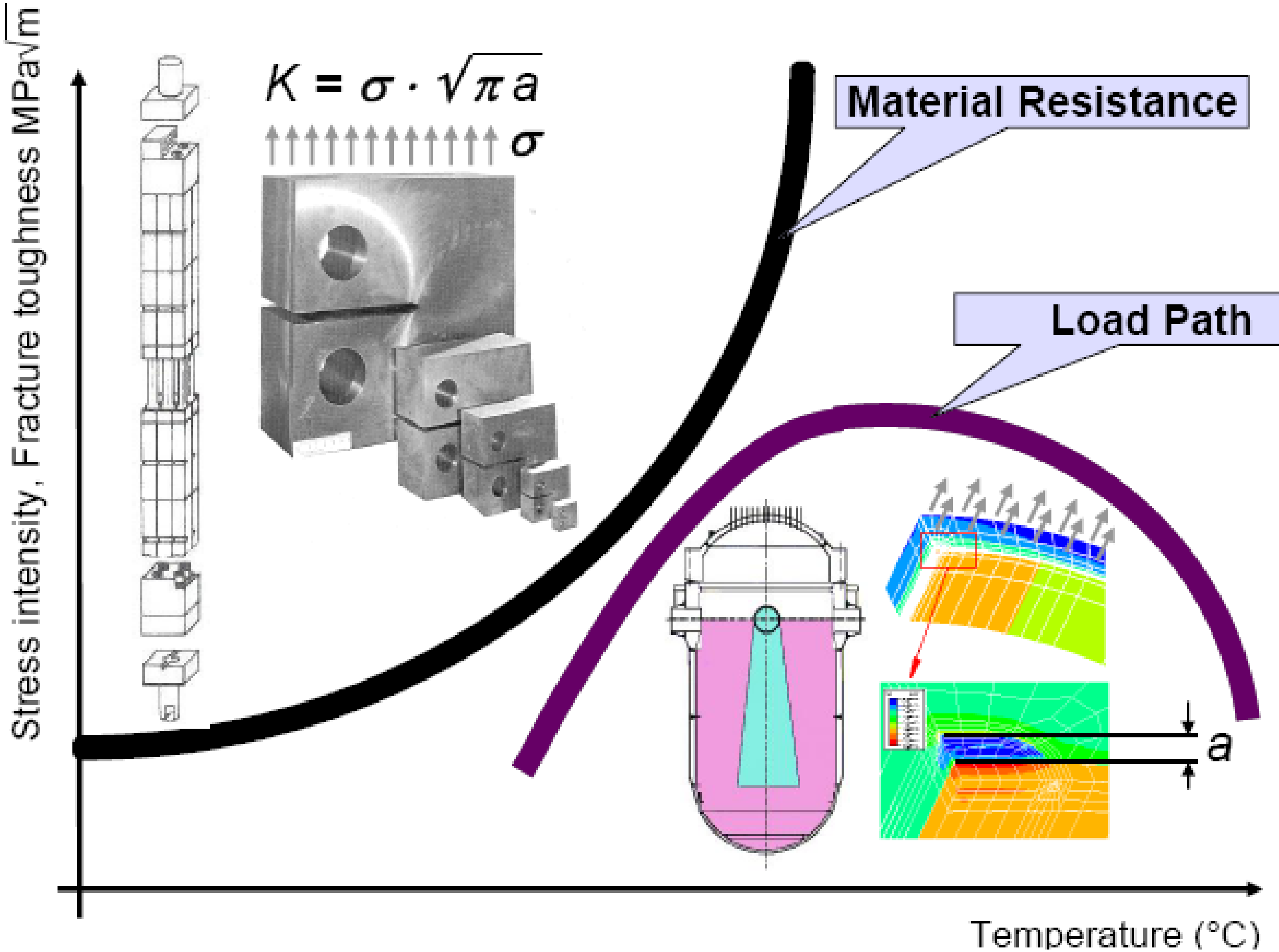
- **Even though RPV material behaviour is plant specific, sensitivity to radiation embrittlement does not depend on the irradiation place, when irradiation conditions are comparable, as it was seen in the previous example when the same weld metal was irradiated in different reactors**

Examples of evaluation



- **Comparison of transition temperature shifts from impact charpy tests and static fracture toughness tests shows that charpy tests are not fully conservative when applying fracture mechanics to RPV integrity**

Examples of evaluation



Conclusion

- **Use of surveillance specimen test results is necessary for ensuring RPV integrity and lifetime, as**
  - Behaviour and properties of all RPV materials are plant specific
  - And code predictive formulae may not be conservative for all materials
- **VERLIFE guidelines describes the procedure for evaluation of results from surveillance specimen test results and their application to RPV integrity and lifetime evaluation**
- **All Czech RPVs in NPP Dukovany and Temelin fulfills the IAEA VERLIFE requirements for surveillance programmes to be applicable and usable for RPV evaluation**

Thank you very much for your kind attention