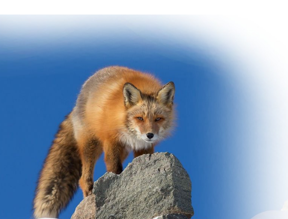
Machine Protection

T N Todd
February 2016

Typical Machine Protection issues

- Plant safety and human safety
- Single parameter limits
- Parameter-combination limits
- Various component temperatures
  - Coils
  - Vacuum vessel
  - In-vessel components
- Plasma impacts
- Positive vacuum vessel pressure
  - Water leaks creating steam
  - Hydrogen deflagration (e.g. due to cryopump regeneration)
- Laser pulse energy (window damage)
- Specific event risk assessments and mitigation strategies
- *Most adverse events relate to stresses, so fatigue limits apply*



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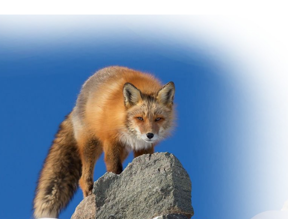
- operational limits of parameter combinations
- impacts of the plasma on the machine
- fault conditions
- need for benign plasma termination procedures



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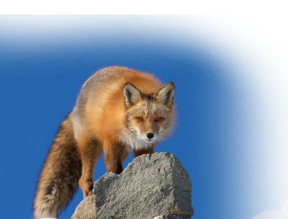

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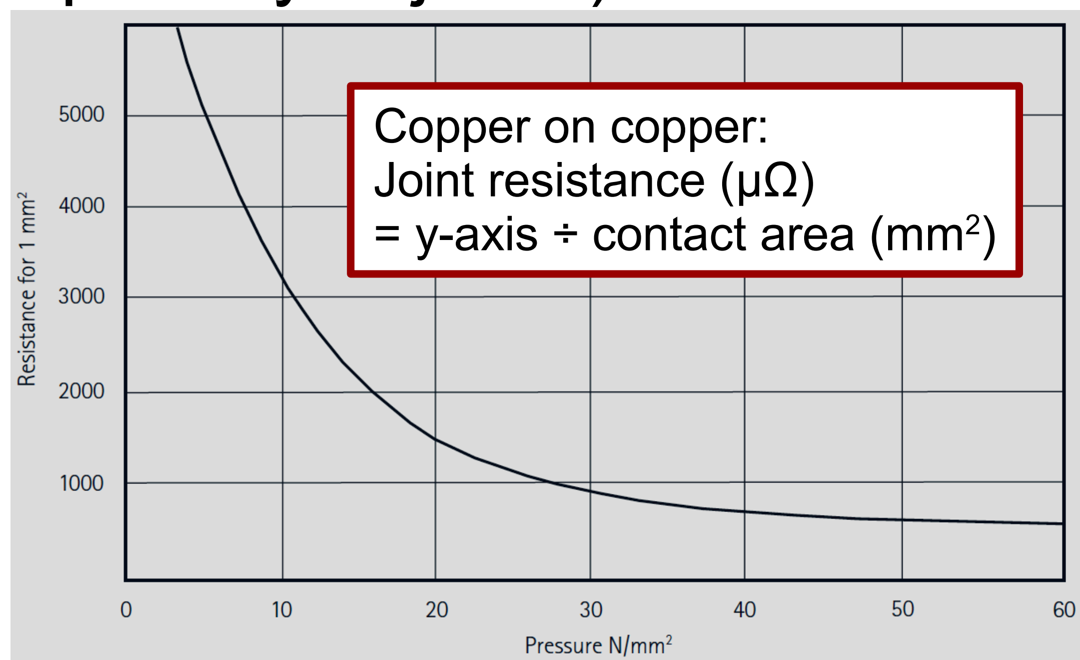

Figure 69 – The effect of pressure on the contact resistance of a joint

http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/jointing.pdf

Section 6.0 - Jointing of Copper Busbars, David Chapman

- Power supply components
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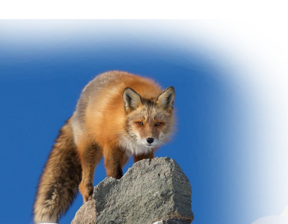

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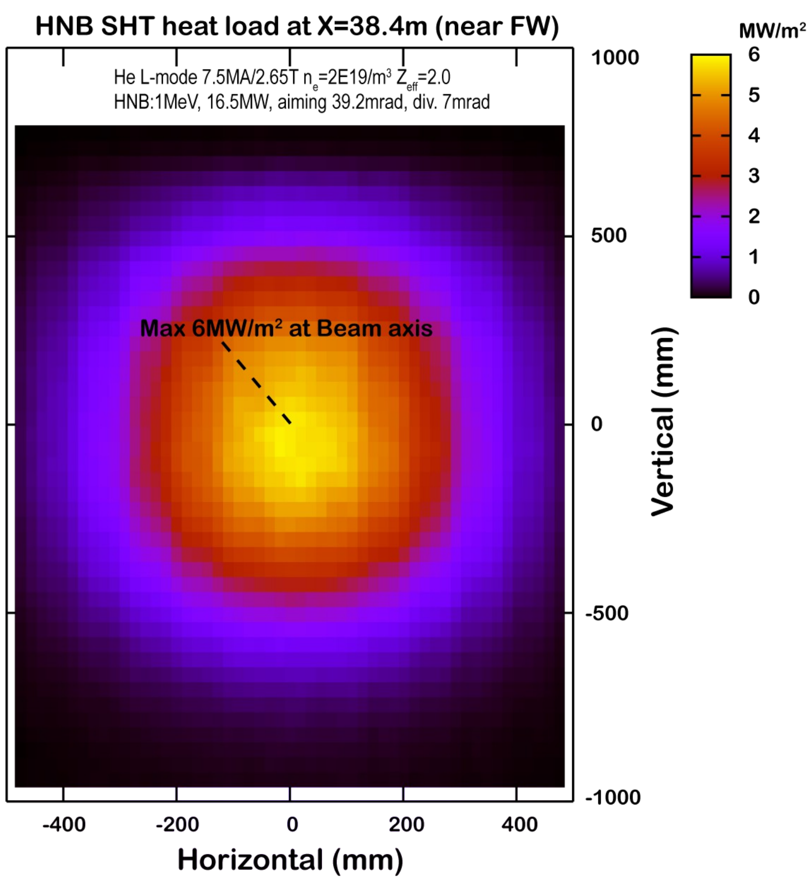

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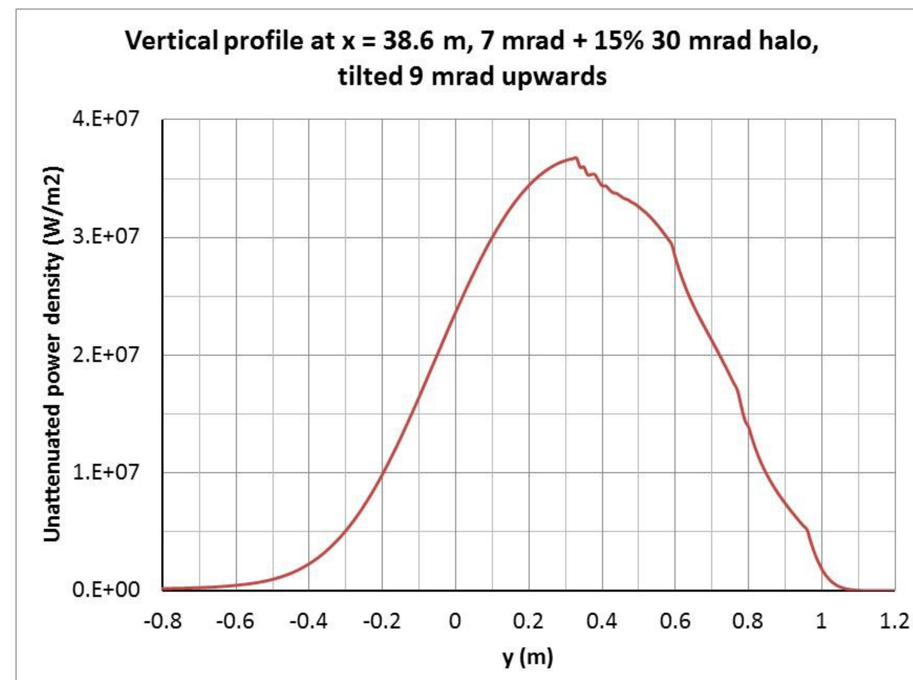

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Changing poloidal fields create eddy currents;
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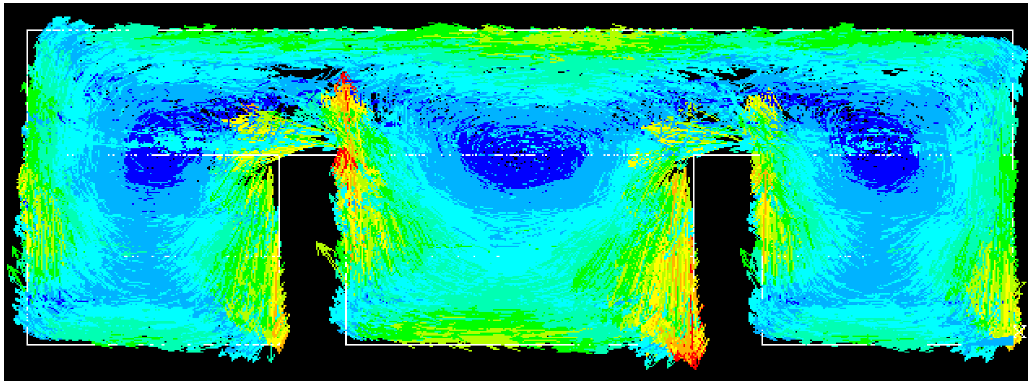

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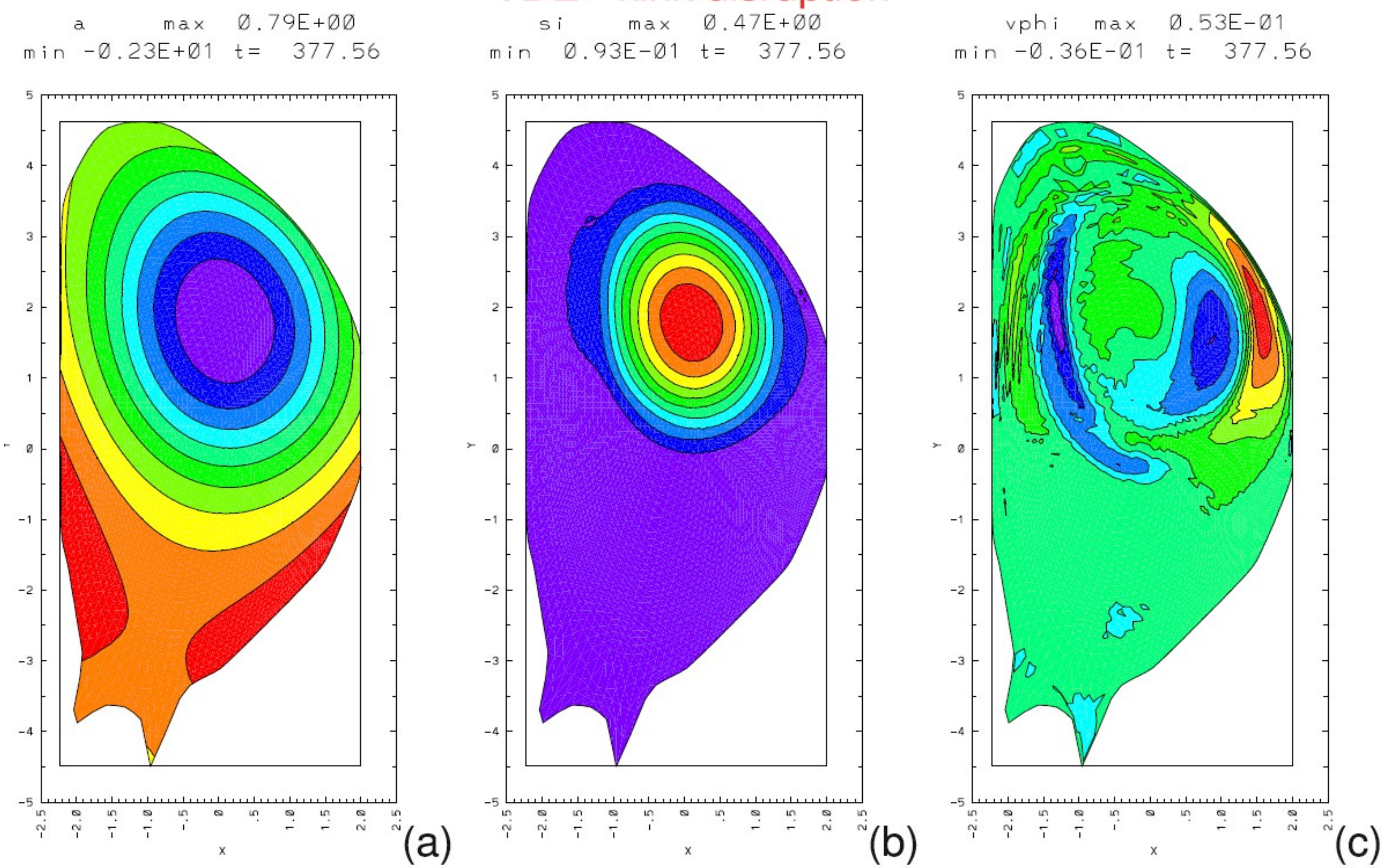

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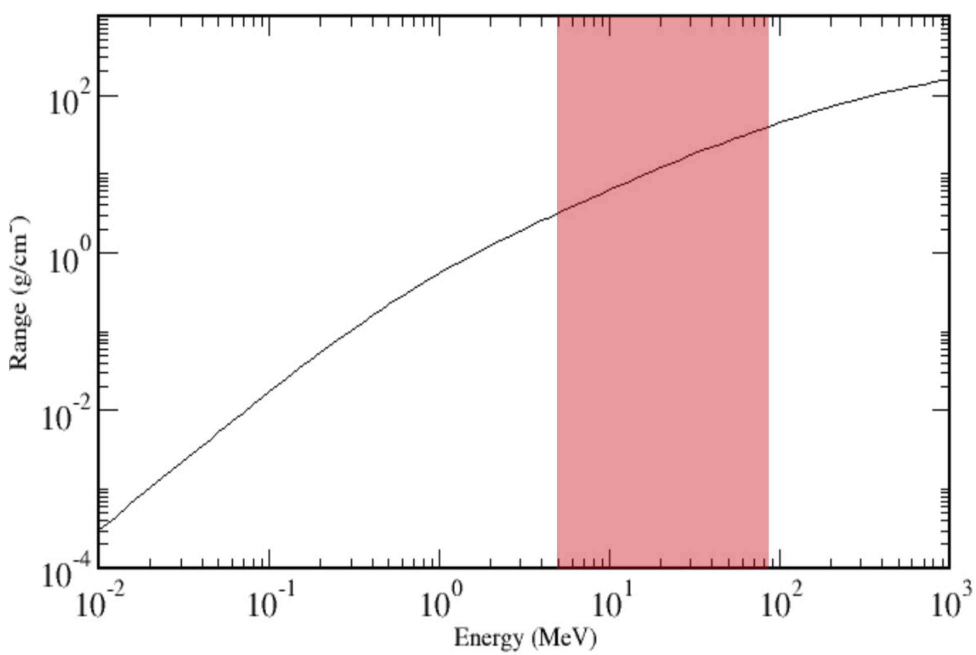

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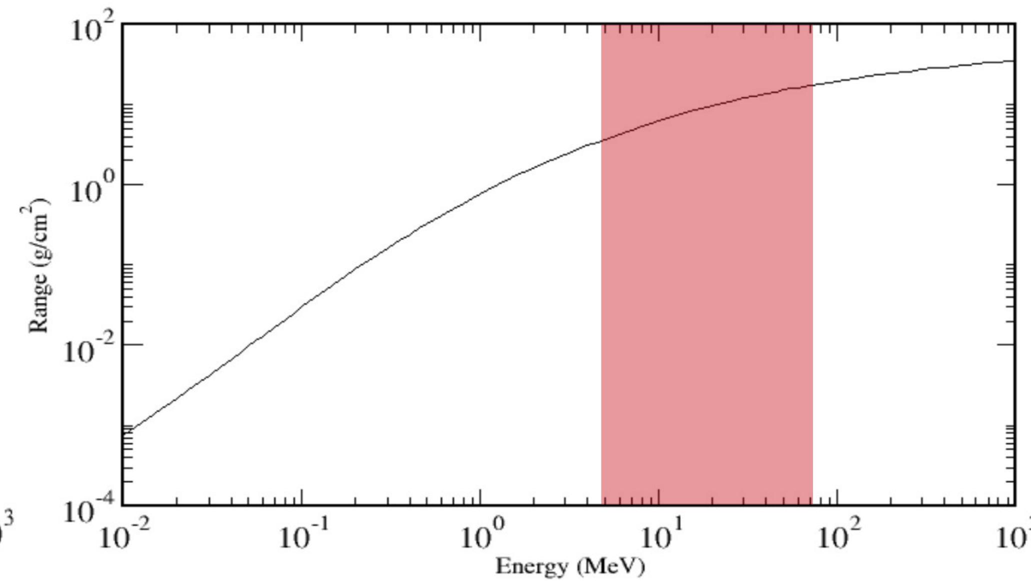

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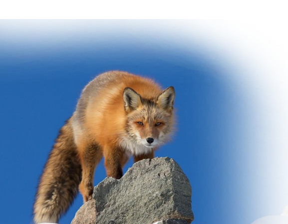

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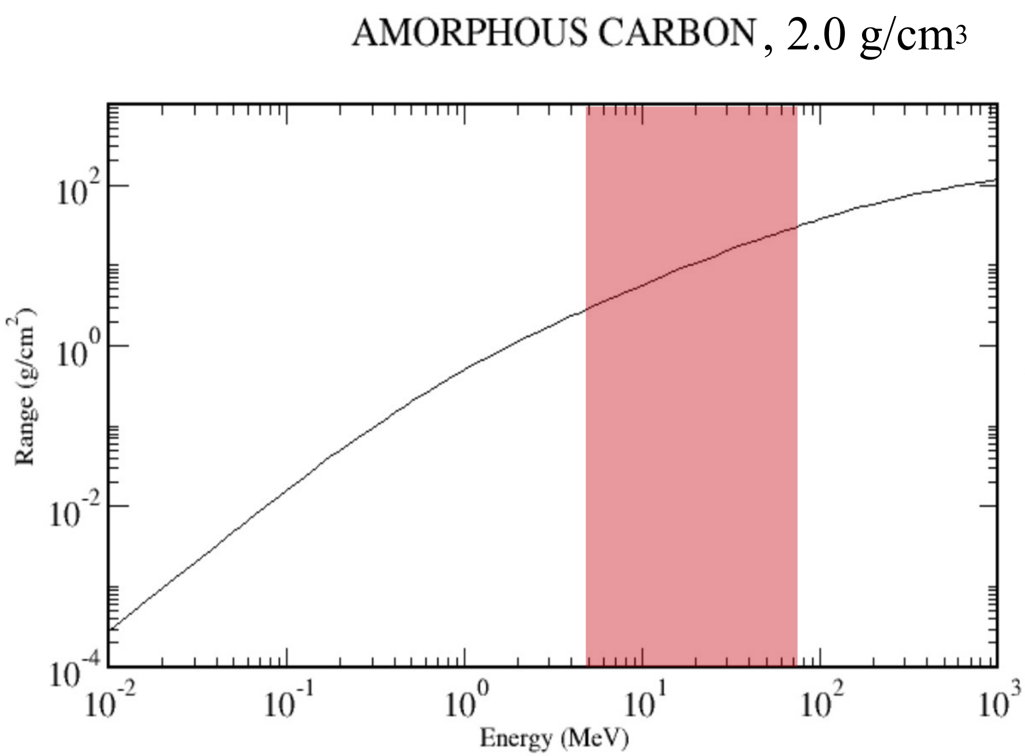

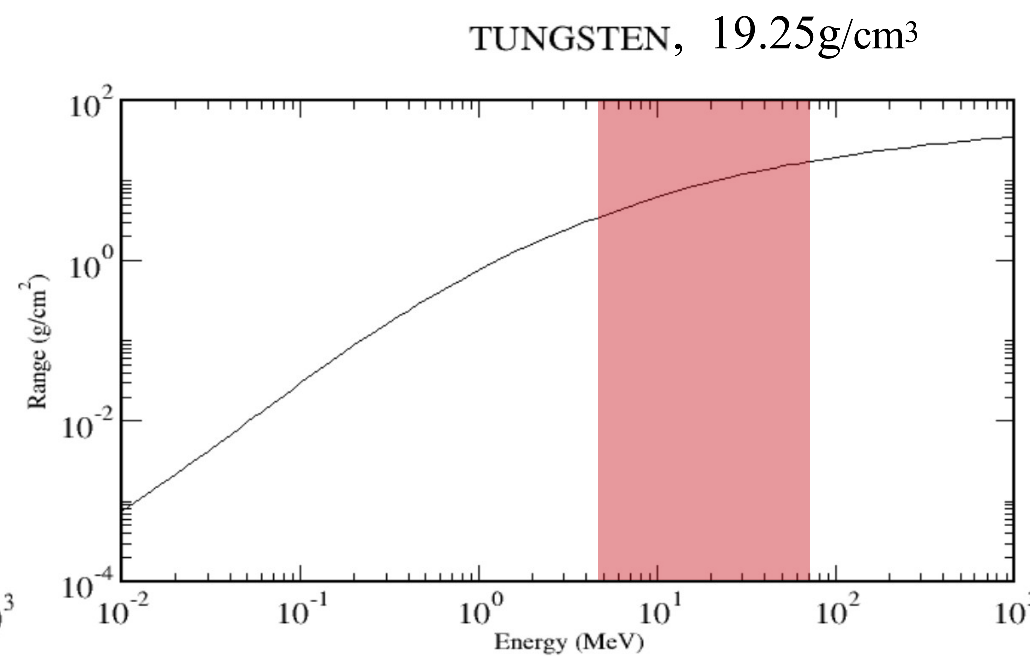

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Machine Protection Panel or similar

A special committee (or else general design reviews) consider the tokamak and all the plant, assessing:

- Failure modes affecting only the failed system
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  - Microprocessors
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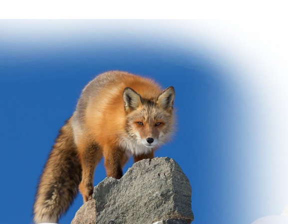

Optimisation of plasma terminations

- Different emerging problems may require different plasma control responses or termination procedures...

Example aspects of JET ITER-Like Wall protection system development

Present JET Controls and Protections

Equipment at Risk	Sensor
Vessel	KC1d Ipl
Vessel	KC1d LC
Vessel, Magnets	PPCC
	PTN
Tiles in NB beam	KG1, KS
Tiles in NB beam	KG1, KS
NB Shinethrough	KG1, KS

N.B. Plasma parameters calc

Present Actions

- PPCC
  - Slow Stop
    - Soft landin
    - Ramp Mag
  - Fast Stop
    - Hard landir sacrifice
- Aux Heat
  - Slow Stop
    - Ramp dow
  - Fast Stop
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- Hard-coded or Exper

ILW – Responses

- PPCC
  - Change Strike Points
  - Avoid Outer / Inner Limiter
- Aux Heat / Fuel
  - NB: Switch off or Swap PINI (psu-paired)
  - RF, LH: Reduce Power, change phase, frequency
  - Gas: Reduce Gas
- *Issues*
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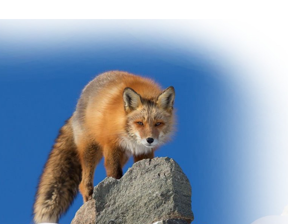
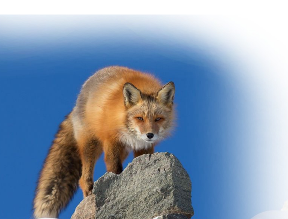
  - *ILW Programme – Performance & Productivity Optimisation*



Conclusions

- Machine protection is a deeply complex subject!
  - Machine Protection discussions can reveal new human safety issues - must involve Safety Group
  - Identify hazardous effects and their causal events
  - Categorise the events for impact and frequency
  - Develop a policy for interlock types to be used, of varying integrity and redundancy (and cost)
  - Agree a hierarchy of trip levels e.g. related to interlock type
  - Set up appropriate benign plasma termination scenarios
  - Review all machine protection systems periodically...
  - ...and whenever a plant modification is made



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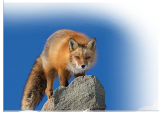

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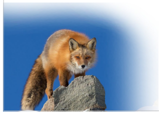

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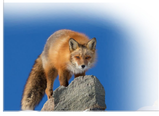

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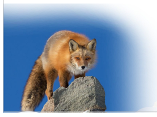

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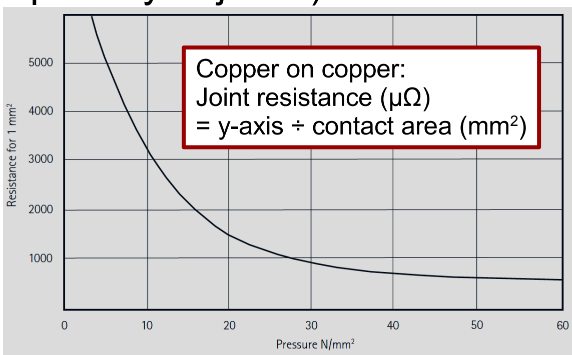

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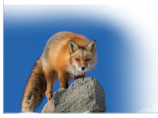

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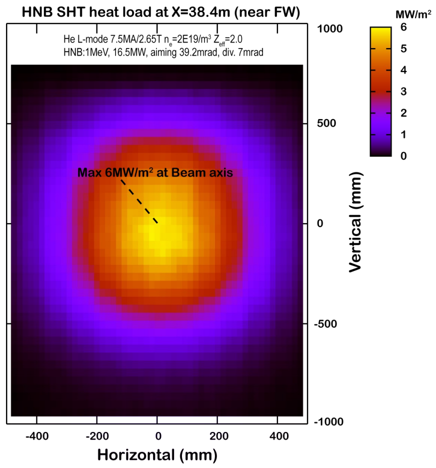

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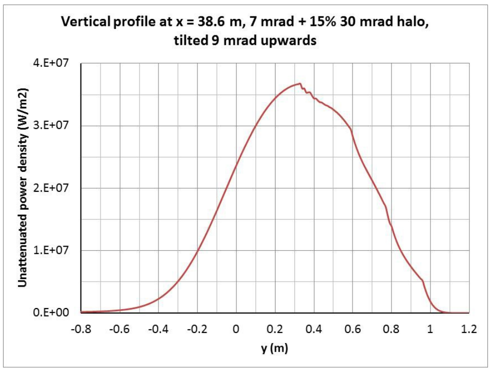

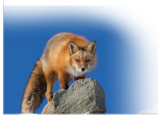

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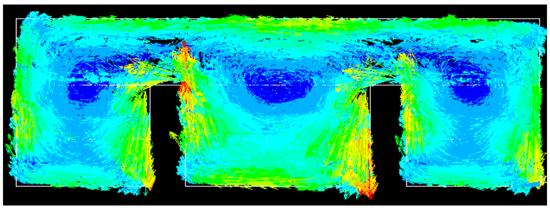

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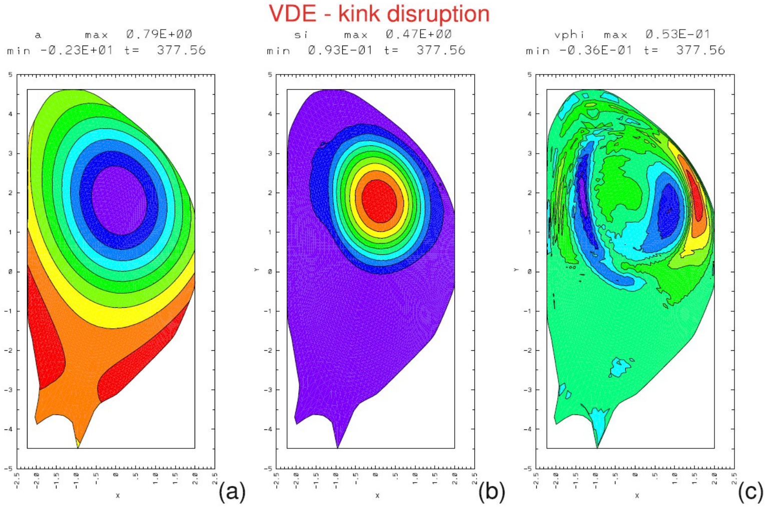

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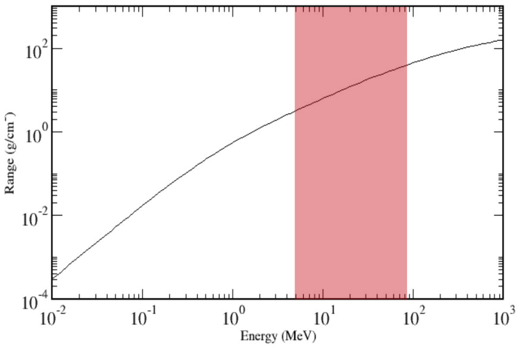

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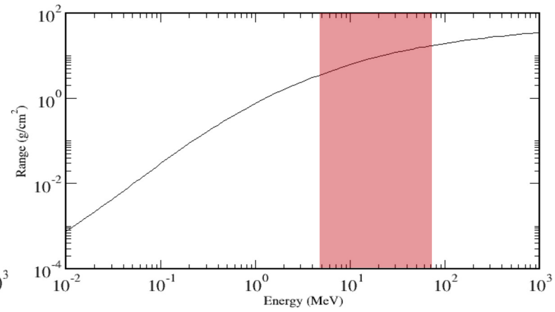

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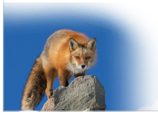

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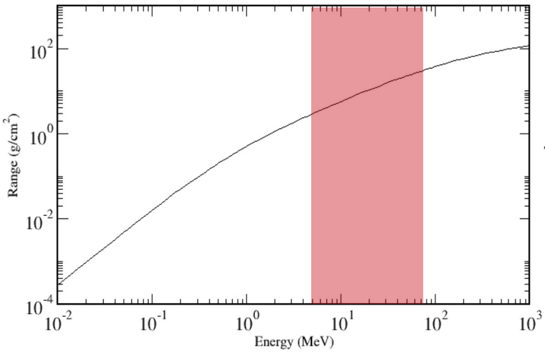
AMORPHOUS CARBON, 2.0 g/cm3



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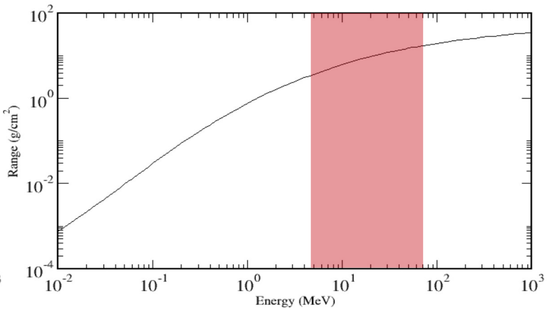

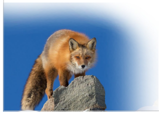

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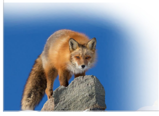

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Vessel, Magnets	PPCC
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NB Shinethrough	KG1, KS

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    - Soft landin
    - Ramp Mag
  - Fast Stop
    - Hard landir sacrifice
- Aux Heat
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    - Ramp dow
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    - Ramp dow
- Hard-coded or Exper

ILW – Responses

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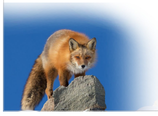
  - *Terminate or Recover ? Predict and Avoid ?*
  - *ILW Programme – Performance & Productivity Optimisation*



Conclusions

- Machine protection is a deeply complex subject!
  - Machine Protection discussions can reveal new human safety issues - must involve Safety Group
  - Identify hazardous effects and their causal events
  - Categorise the events for impact and frequency
  - Develop a policy for interlock types to be used, of varying integrity and redundancy (and cost)
  - Agree a hierarchy of trip levels e.g. related to interlock type
  - Set up appropriate benign plasma termination scenarios
  - Review all machine protection systems periodically...
  - ...and whenever a plant modification is made