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International Centre for Theoretical Physics

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Joint ICTP-IAEA Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events

19 - 23 April 2010

Effects of Extreme Weather on Nuclear Power Plants

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Effects of Extreme Weather on Nuclear Power Plants

Presented by Oszvald Glöckler
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Trieste, Italy

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Nuclear Power Plants (NPPs)

- NPPs are large “outdoor machines”
- NPPs are “hooked-up” to water, air, electricity, and transport road networks
- Safe Operating Envelope

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Examples of extreme conditions

- Drought – reduction in availability of cooling water, service water
- Heavy downpour – flashflood – clogged drainage system
- Lightning – power outage, fire, structural damage
- Strong wind – structural damage to plant and electric grid
- Sandstorm, dust – China, Iran, UAE, …?

Site evaluation
– long term needs

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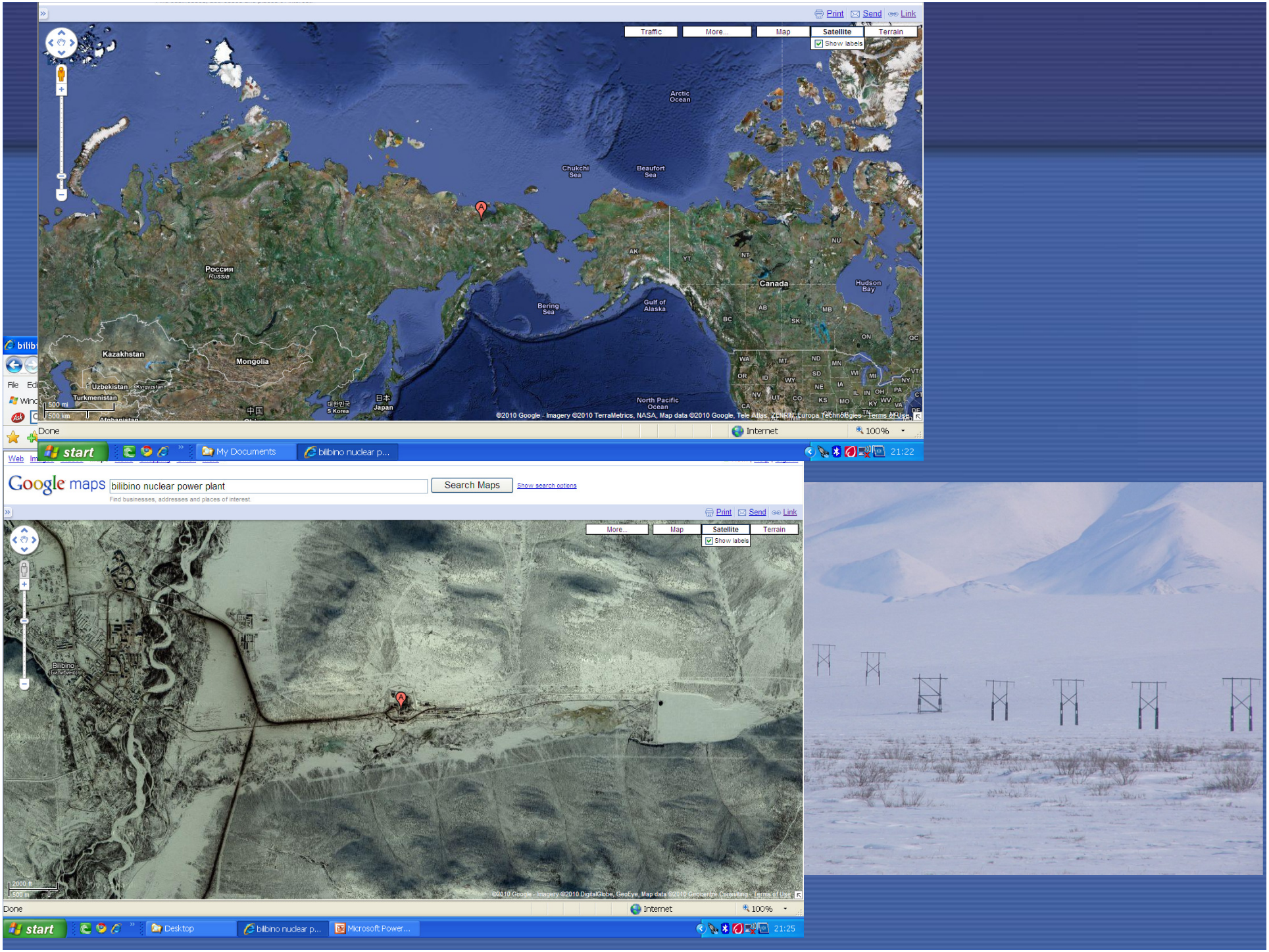
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Examples of extreme conditions

- High temperature – low steam turbine effectiveness (low temp. reservoir, low pressure)
- High temperature – biological growth

- Low temperature – heavy snow, ice storm - extra weight load on power lines and structures; freezing structures, blocking access to NPP site

- Hurricane
- Tsunami
- Tornado – Davis-Besse NPP 1998
- Mudslide – Brazil 2010

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What do NPPs need?

	Normal Operation	Safety Systems
Clean cooling water	Steam Turbine	Emergency cooling
Clean air	Ventilation	Emergency diesel generators
Reliable electric grid	Deliver power to grid	Powering safety systems from off-site power source
Personnel	Operation/maintenance	Emergency response teams
Access to transportation routes	Normal movement of staff and materials	Emergency response equipment and teams

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IAEA Safety Guides

- “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”, NS-G-1.5 (2003)
- “Meteorological Events in Site Evaluation for Nuclear Power Plants”, NS-G-3.4 (2003)
- “Flood Hazard for Nuclear Power Plants on Coastal and River Sites” NS-G-3.5 (2003)
- “External Human Induced Events in Site Evaluation for Nuclear Power Plants”, NS-G-3.1 (2002)

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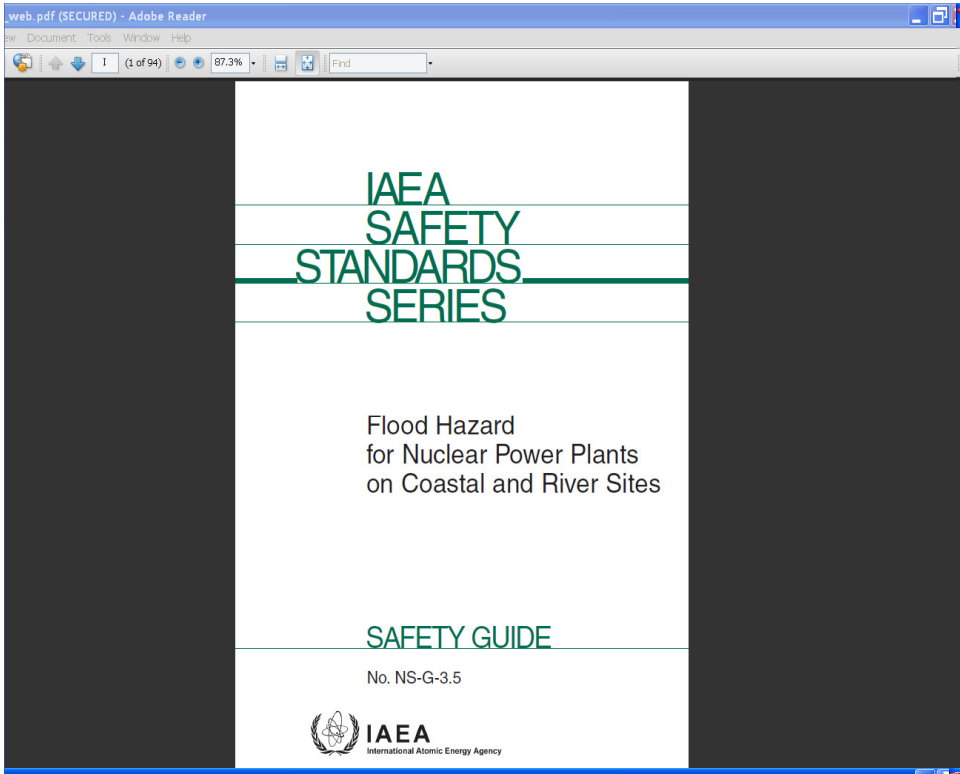
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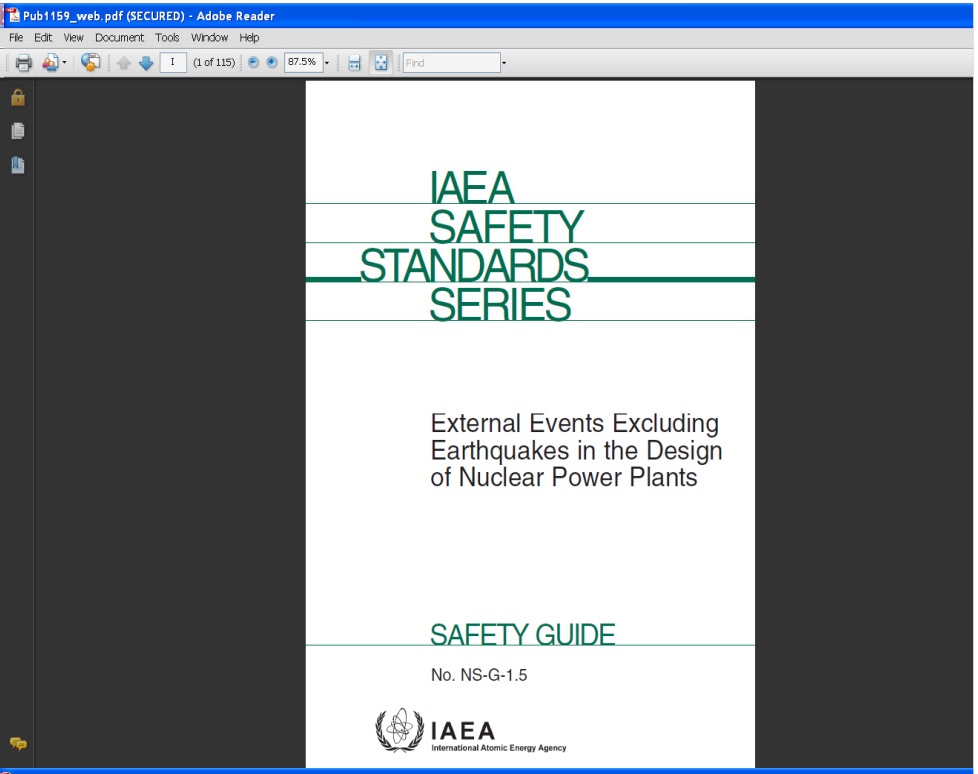
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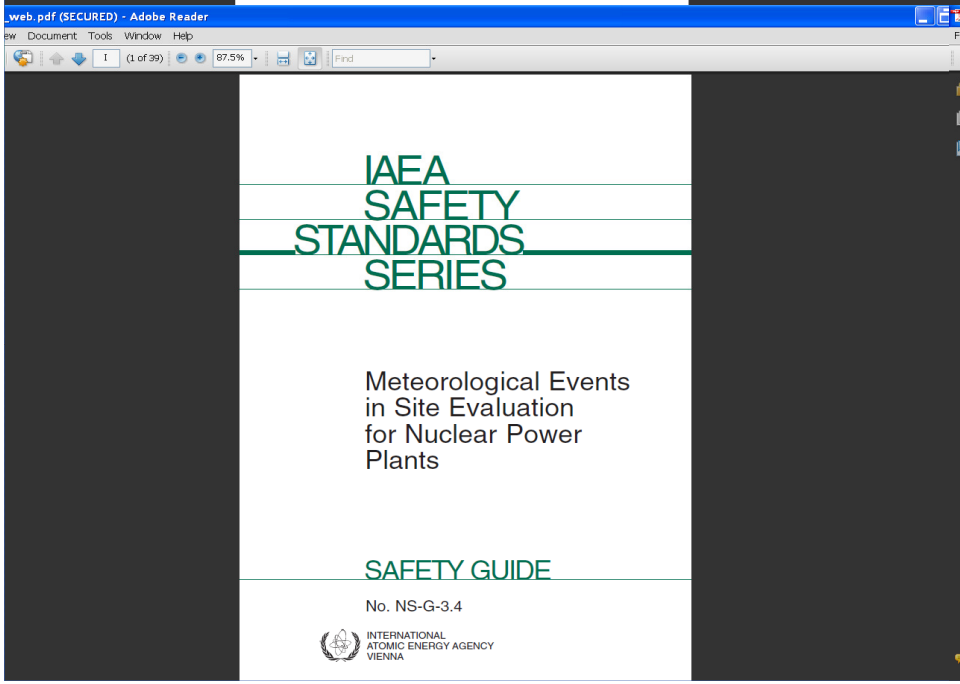
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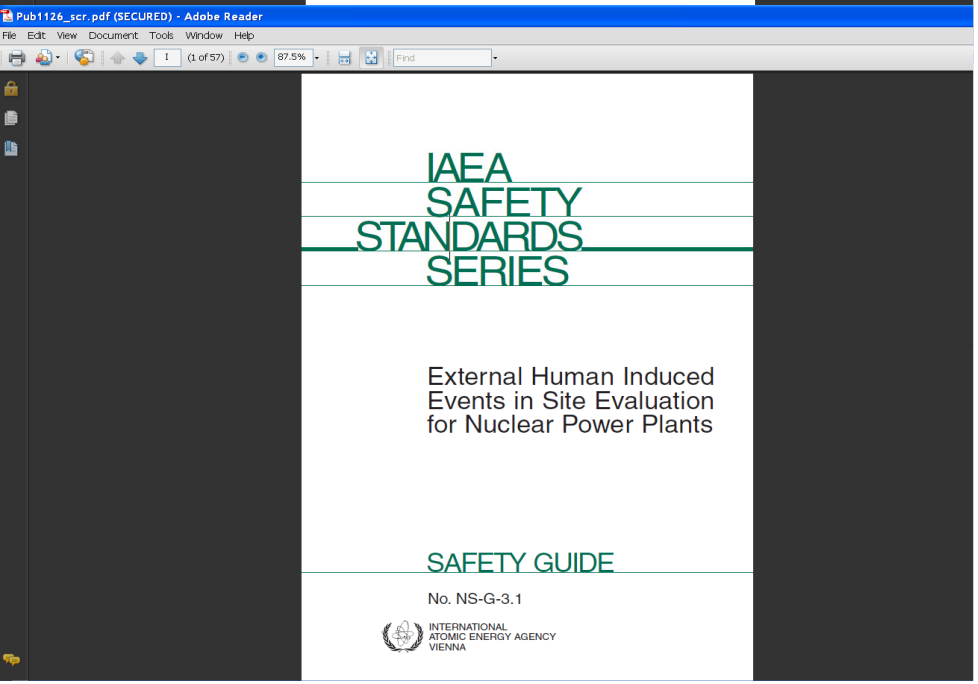
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Design Basis External Events (DBEE)

- Human induced
- Natural

Natural DBEE

- Extreme meteorological conditions
- Floods
- Winds
- Abrasive dust and sand storms
- Lightning
- Volcanism
- Biological phenomena
- Collision of floating debris with safety related structures

External event category 1 (EE-C1):

- Important to safety
- Items whose functioning should be maintained in the event of the DBEE
- Items required for preventing or mitigating plant accident conditions for such a long period that there is a reasonable likelihood that a DBEE may occur during that period

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External event category 2 (EE-C2):

- Items whose loss of functionality may be permitted but should not impair the functionality of EE–C1 items in the event of a DBEE

External event category 3 (EE-C3):

- Items that are parts of systems that may generate events with radiological consequences different from those generated by the reactor (e.g. spent fuel building and radioactive waste building)

External event, non-classified (EE-NC): All other items.

Meteorological Events important to NPP Operation and Site Evaluation

1. Extreme values of meteorological variables
2. Rare meteorological phenomena

1. Extreme values of meteorological variables

- Strong wind
- Rain
- Snow pack
- High/low temperature
- Sea water level

2. Rare meteorological phenomena

- Tornadoes
- Hurricanes
- Tropical cyclones
- Lightning
- *Ice storm (freezing rain)*

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- Data collection for determining the meteorological characteristics of the NPP site
- Design bases for protection against meteorological hazard at/near NPP site
- Possible effects of climate change for the whole lifetime of the NPP (60-80 years)

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Strong Wind

Extreme wind can affect
- power supply
- availability of electric grid
- damage to switchyard

Pressure differential can
- create false signals to instrumentation
- affect the ventilation system

Dust and sand carried by wind can
- damage exposed surfaces
- prevent the functioning of equipment

Heavy salt sprays from sea can
- created shocks in exposed electrical equipment
- long-term effect of corrosion

Strong Wind

Increased force on structures

- structural damage of large structures susceptible to wind
- collapse of cooling towers, chimneys, and high rising cranes
- group effect – combination of the influence of neighbouring structures
- adequate separation
- wind induced missiles

Ferrybridge power station, 1 November 1965

- three of the eight cooling towers collapsed due to wind-induced vibrations
- the structures had been built to withstand higher wind speeds
- shape of the cooling towers casued winds to funnel into the towers themselves, creating creating a vortex

Cooling towers with malfunctions can freeze during very cold weather.

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Strong Wind

Loading parameters are

- wind strength
- gustiness and
- persistence

Combinations of wind induced loads with other external effects (design loads) should be considered

- Wind-rain-flood
- Wind-low temperature-snow-ice
- Wind-high temperature-drought-sand storm

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Cold winter in Ontario

Heavy snowfall
- access to NPP site by personnel
- access to facilities within the NPP site
- Land of horizontal snow: Bruce Power NPPs

Ice storm, freezing rain
- access to NPP site by personnel
- extra weight load on power lines and towers
- Increased cross section against wind
- Ice storm of January 1998

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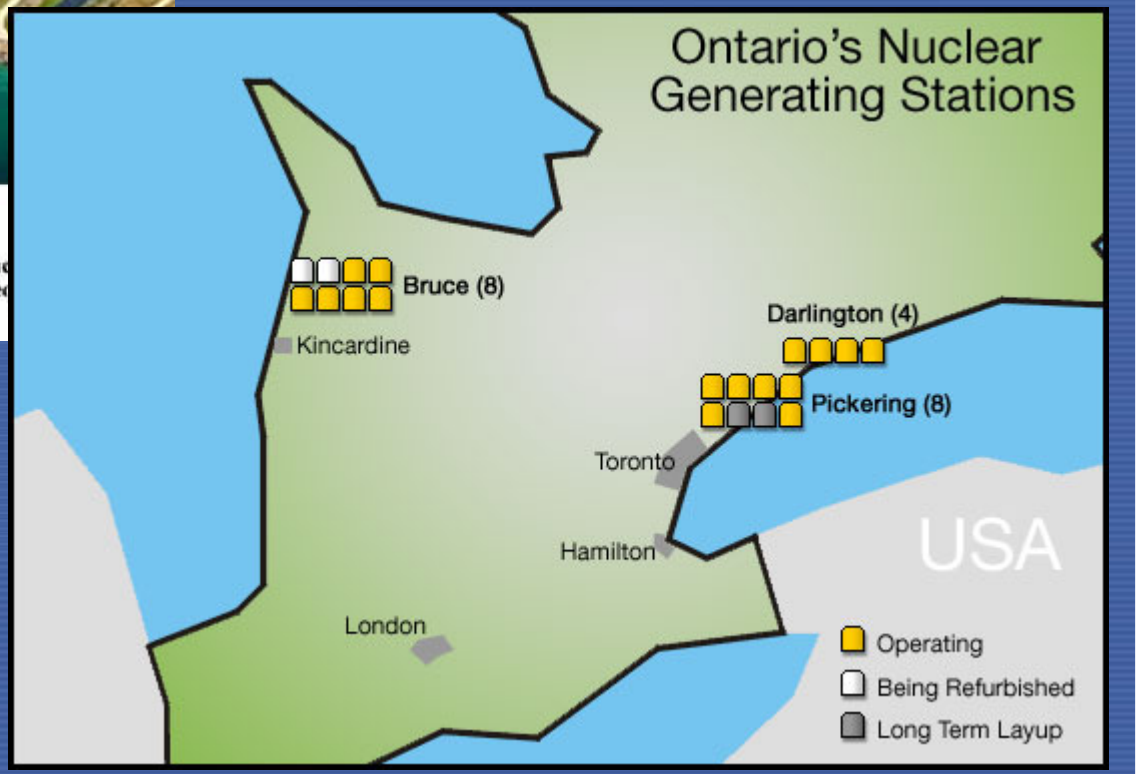
Bruce Power
Located in Ontario, Bruce Power's four operating nuclear power plants produc
electricity for a city the size of Toronto. Cameco, as partner provides all fuel re



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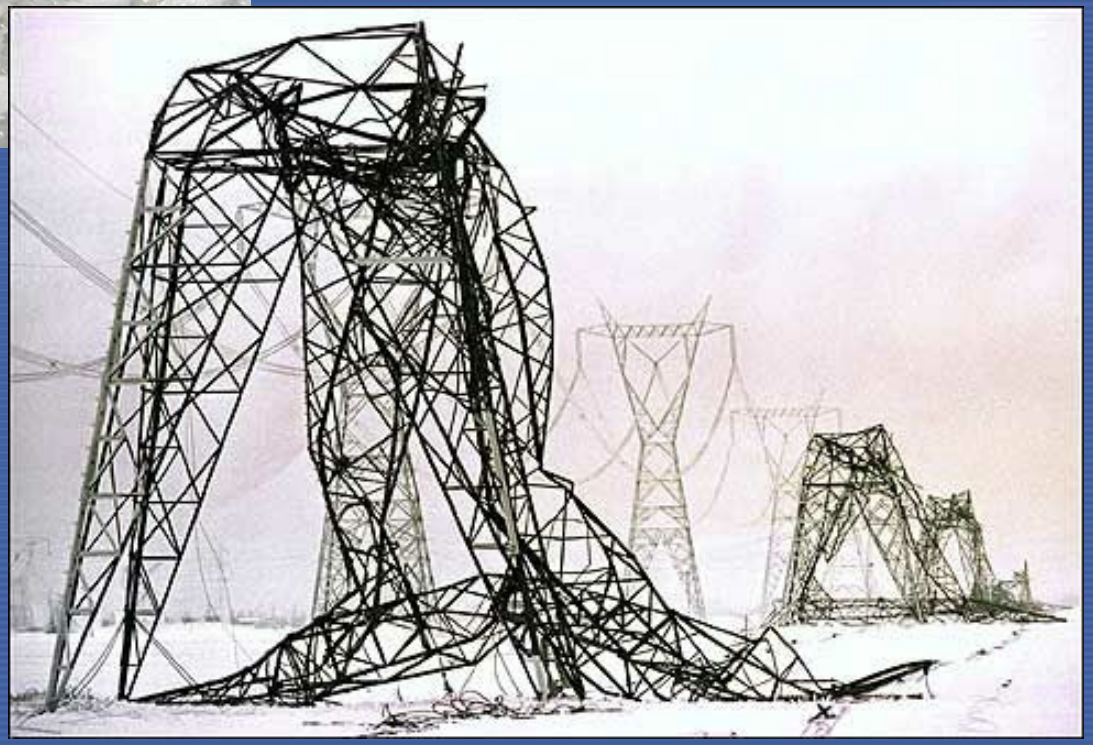

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Cold winter in Ontario

Prolonged extreme cold temperature

- ventilation shafts could not be closed
- freezing pipes – raptures
- water damage in I&C rooms at lover elevations

Secondary effects of cold winter

- Corrosive effect of road salt
- Depression (far fetched)

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Biological Phenomena

Main problem caused by biological effects:

- Reduced availability of cooling water and service water
- Caused by excessive growth of algae, mussels or clams, clumps of seaweed, large quantities of fish or jellyfish clogging water intakes
- Clogging of water intakes for safety related heat exchangers must be prevented
- Installing fixed or rotating drum screens and redundant paths for clean cooling water
- Cooling water in condensers and heat transport systems should be treated to inhibit the growth of organisms within cooling circuits

Other hazards causing blockage of water intakes: Floating ice and flood debris

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Biological Phenomena

Additional biological effects:

- Malfunction in ventilation systems caused by leaves or insects clogging air filters
- Cables of instrumentation, control, and power supplies attacked by rats or bacteria
- Corrosion and accelerated ageing of steel structures by sulphate reducing bacteria

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External Fire

Smoke from bush or forest fire

- Ventilation systems affected by smoke and heat (CCF)
- Diesel generators air intake for combustion (safety function - CCF)
- Safety I&C vulnerable to smoke and dust should be isolated (CCF)
- Reduced visibility and site accessibility

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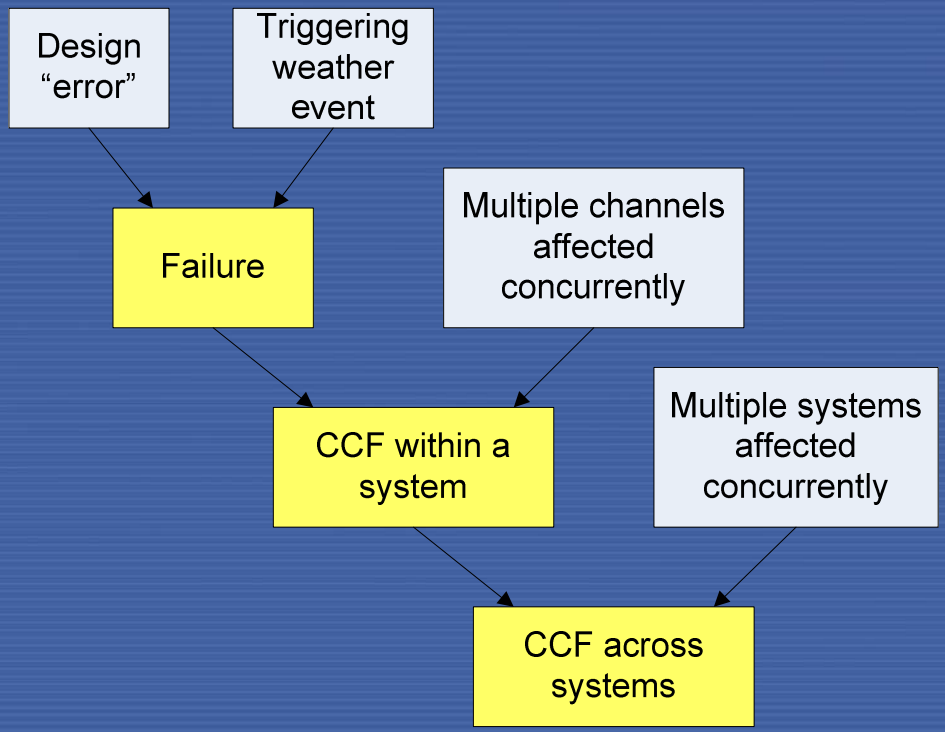
Conditions required to create a common-cause failure (CCF)

Design error or limited design basis +
Triggering event (extreme weather condition)
= Failure



External effect beyond design basis, for which redundancy and single failure criteria were not followed.

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Zebra Mussel Sightings Distribution
Dreissena polymorpha
Zebra mussel occurrences
Zebra mussels trailered overland on boat hulls
Map produced by the U.S. Geological Survey, Gainesville, Florida, April 1, 2005.

Point Lepreau NPP in New Brunswick, Canada

CANDU-6

Bay of Fundy between New Brunswick and Nova Scotia

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MAINE
St. Stephen/ St. Andrews
Saint John
Hants County
St. George/ Lepreau
Kings County
Grand Manan/ Campobello
NOVA SCOTIA
Machias/ Eastport
Annapolis County
Pleasant Bay
Bar Harbor/ Acadia
Digby
Yarmouth

Nuclear specific

- Need for reliable electric grid
- Diverse, independent, redundant safety systems (to prevent common cause failures)
- Need for long-term core cooling
- Physical protection and security

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Primary effects of extreme weather on NPP operation & safety

- All direct effects previously discussed

Secondary effects on NPP operation & safety

- Indirect effect through unreliable electric grid due to weather effects on other stations and lines (wind, water)
- Indirect effect by increased demand due to extreme weather (heat, cold)
- Changes in demand pattern → outage windows, “quiet modes”

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