Distributed Intelligence System for Online Action-Taking in Non-Anticipated Situations in Nuclear Power Plants

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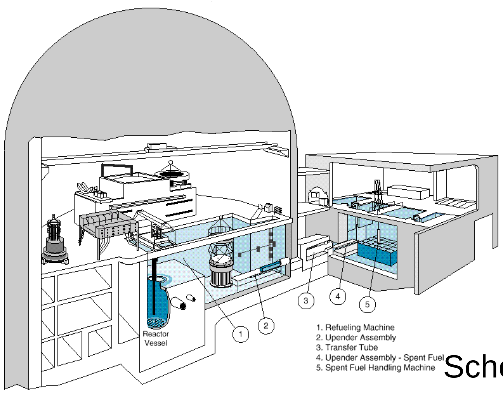
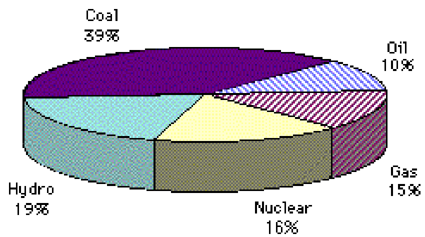
Outline

- Nuclear Power Renaissance
- Planning in Nuclear Industry
- Architecture of System
- Distributed Planning
- Conclusions

Nuclear Power Renaissance

- 439 nuclear reactors (31 countries)
- 33 new reactors, over 100 in planning
- Over 12,000 years of operating experience
- Nuclear reactors supply 16% of the world's electricity as base-load power (372,000 MWe of total capacity)
- 284 research reactors (56 countries)
- 220 reactors for ships and submarines



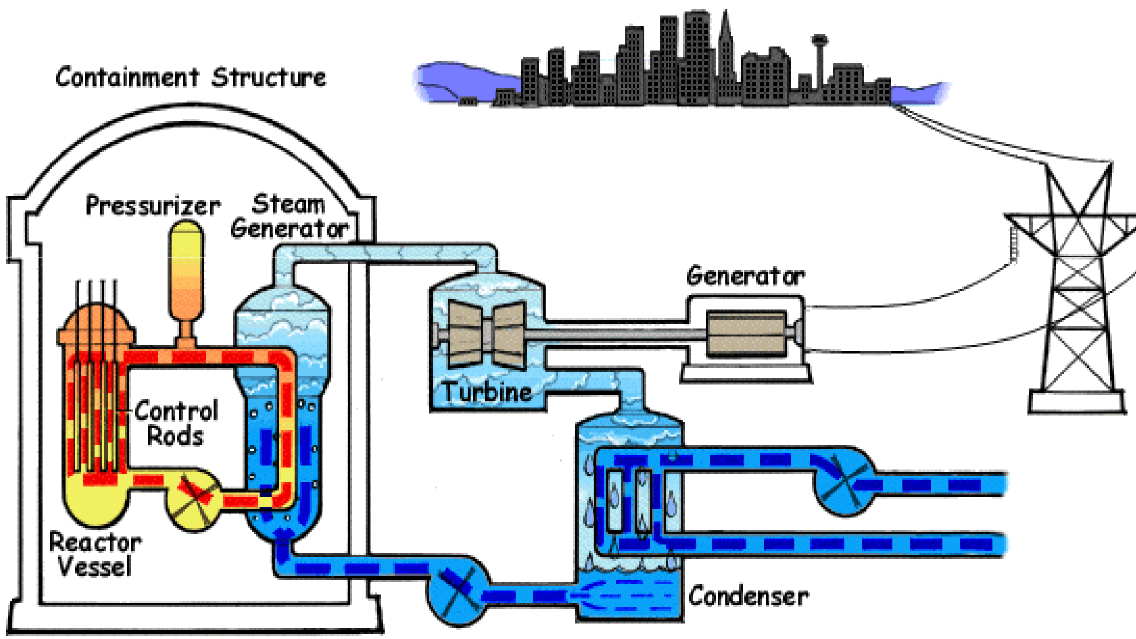


Global Nuclear Power

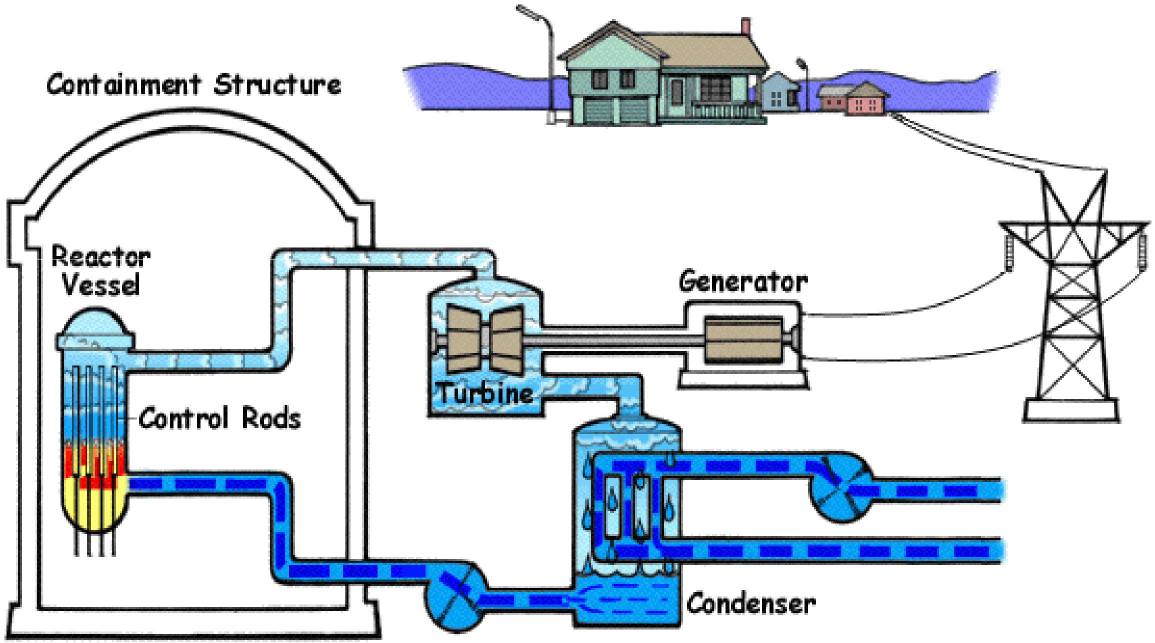
Electricity Generated	Reactors Operating	Reactors Building	On Order or Planned	Proposed
16% 2658 TWh	439 (372 GWe)	33 (27 GWe)	94 (101 GWe)	222 (193 GWe)

Sources:
Reactor data: WNA to 17/10/07.
IAEA- for nuclear electricity production & percentage of electricity (% e) 5/07.
WNA: Global Nuclear Fuel Market (reference scenario) - for U. Includes first cores for new reactors.
Operating = Connected to the grid;
Building/Construction = first concrete for reactor poured, or major refurbishment under way (* In Canada, 'construction' figure is 2 laid-up Bruce A reactors);
Planned = Approvals, funding or major commitment in place, mostly expected in operation within 8 years, or construction well advanced but suspended indefinitely;
Proposed = clear intention or proposal but still without firm commitment. Planned and Proposed are generally gross MWe.
TWh = Terawatt-hours (billion kilowatt-hours), MWe = Megawatt net (electrical as distinct from thermal), kWh = kilowatt-hour

PWRs


Containment Structure
Pressurizer
Steam Generator
Control Rods
Reactor Vessel
Turbine
Generator
Condenser

BWRs


Containment Structure
Reactor Vessel
Control Rods
Turbine
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Condenser

Automated Planning & Scheduling in Nuclear Industry

- *Promising Field for Applications of Planning &Scheduling techniques due to:*

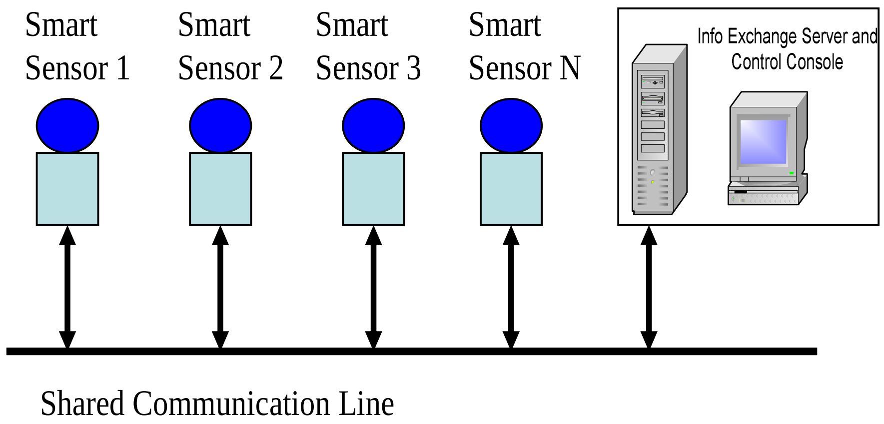
  > Radiation exposure does not allow humans to visit all sites in a plant
  > High Temperature makes difficult the access to humans
  > Need for diagnostics and prognostics
  > Reactor Safety and Plant Surveillance
  > Small amount of time to react to non expected situations
  > In emergencies, machines do not panic & make decisions under no pressure
  > Plants are huge complex systems and need monitoring 7/24
  > For slow, localized and meaningless events P&S can save time and resources

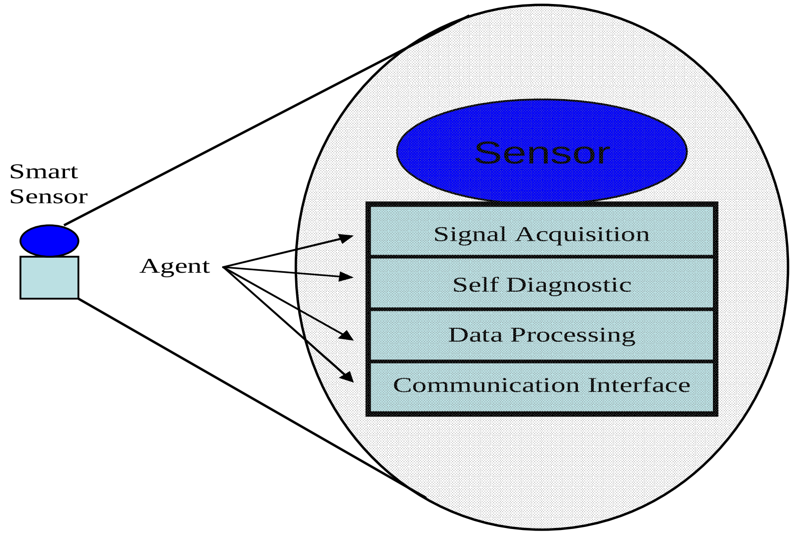
- Up to this point not much research for P&S has been done

Architecture of the System

Distributed System: >> *A Central Processing Console*

>> *Sensors Embedded with Intelligent Agent* (Smart Sensors)

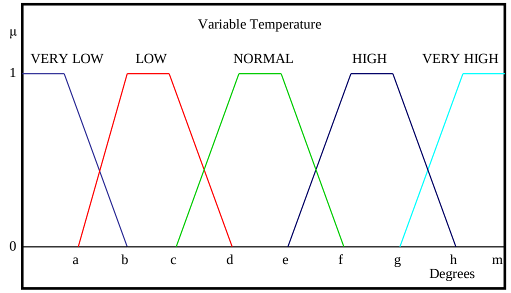




Distributed Planning Method

- Two stage Planning:
  - i) Planning at the sensors performed by agents (Agent Planning)
  - ii) Planning at Central Console performed by Processing Module

- Use of **Fuzzy Logic** for:
  - representation of empirical knowledge in each sensor and central console (fuzzy rules)
  - detection of non anticipated situations by fuzzification of the sensor measurements



Fuzzification of Temperature

- *First local agent planning* and if it fails then the control is transferred to *Central Console for Central Planning* (never fails, since it might lead to scram of reactor)

- **Goal:** Find a series of actions among its embedded fuzzy rules so as to deal with the non anticipated situation.

Agent Planning

- ***Initial state:*** Abnormal measurement
- ***Restrictions:*** Limited Resources.
  Limited Actions can be taken
- ***Actions:*** Look up correlation between sensors.
  Talk to relevant sensors (defined by correlations).
  Wait for their values.
  Inputs the received values to its fuzzy inference mechanism.
  Activation of fuzzy rules.
  Put the rules in an order according to their degree of membership *(membership planning)*
  Look for resources to satisfy the plan
- ***Final States:*** i) Series of actions leading to stable state
  ii) Transfer control to Central console (if limitation of resources)

Central Planning

- ***Initial State:*** Current State after receiving an alert from sensors
- ***Restrictions:*** Correlations among sensors
- ***Actions:*** Look up correlations among sensors

  Firing of fuzzy rules and order of them according to degree of membership (membership planning)

  Define alternative paths.
- Final States: i) Stable state of nuclear plant

  ii) Shutdown of the reactor

Membership Planning

PLAN and Scheduling of Actions for Most Possible Scenario: A

Initial state: abnormal measurement

Conditions >> Values coming from sensors

Restrictions: Available rules

Plan:

i)If variable_1 is H1 and variable_2 is H2 then do action_1 with confidence C1.

ii)If variable_1 is H1 and variable_3 is H3 then do action_2 with confidence C2.

iii)If variable_4 is H4 and variable_2 is H2 then do action_3 with confidence C3.

…

xx)If variable_4 is H4 and variable_N is HN then do action_1 with confidence C1.

with C1 > C2 > … > CN

Novel Example Case

- ***Scenario:*** *A Reactor Control Rod is stuck while moving into core!*

- Power sensor gets a non anticipated measurement.
- Communicate with the correlated sensors.

- Temperature sensor replies that temperature is High.
- Temperature sensor of reactor coolant replies that temperature is High.
- Fuel clad temperature is Very High.

- The agent uses these values to fire the rules of actions.
- Realizes that has no resources. Problem is not local.

- Control to Central Console.
- Records the current status of variables and fires the appropriate rules. Plan is ready.
- Actions are taken: Another Control Rod moves into core.

Conclusions

- Planning for reactor safety.
- Two stage planner: Agent and Central Planning.
- Effective for local events up to resources limitations.
- Central Planning only in high emergency situations.
- All actions and knowledge are represented through fuzzy sets.
- Membership planning: According to measurement a degree of membership is given to each action. Series of actions consist of the plan.
- If problem is detected by two sensors then control is transferred to central planner, since the non anticipated problem is not localized.