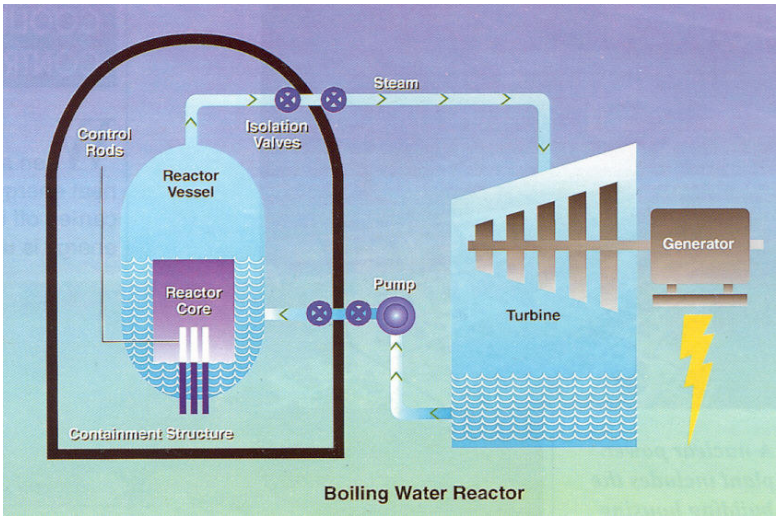
Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

issue brief

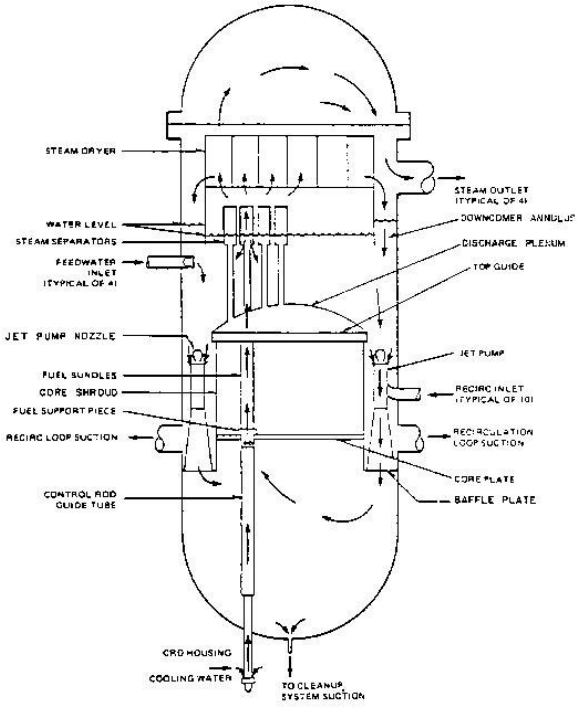
SNAP, CRACKLE, & POP:
THE BWR POWER UPRATE EXPERIMENT

EPU. The Nuclear Regulatory Commission believes it stands for Extended Power Uprate where the agency relicenses a nuclear power reactor to operate at a significantly higher power level.[1] But trials and tribulations at nuclear power reactors over the past two years strongly suggest that EPU really stands for Experimental Power Uprate. The Experiment underway in Illinois may soon move to Vermont.

The Quad Cities Nuclear Power Station is located on the Mississippi River about 20 miles northeast of Moline, IL. The NRC licensed its two boiling water reactors (BWRs) on December 14, 1972.[2] Twenty-nine years later – almost to the day – the NRC amended the licenses to permit the reactors to operate at nearly 20 percent higher output.



As illustrated in the color schematic, energy released from the reactor core of a BWR boils water. The steam spins a turbine connected to a generator to make electricity.



The outline drawing shows the components inside the reactor vessel above the reactor core that process the steam before it flows to the turbine. The steam leaving the reactor core carries little droplets of water. The steam passes through vertical tubes called 'steam separators' that remove many of the droplets. The drier steam then weaves its way back and forth through a metal maze called the 'steam dryer.' When all is working right, water droplets form less than one-tenth of one percent of the steam leaving the reactor vessel.[3]

On March 5, 2002, the Experimental Power Uprate began at Quad Cities when workers reconnected Unit 2 to the electrical grid following a refueling outage. After operating nearly 30 years up to the original licensed power level, the plant literally began shaking itself apart at the higher power level. Workers manually shut down Unit 2 on March 29th after high vibrations caused leaks in the control system for the main turbine.[4]

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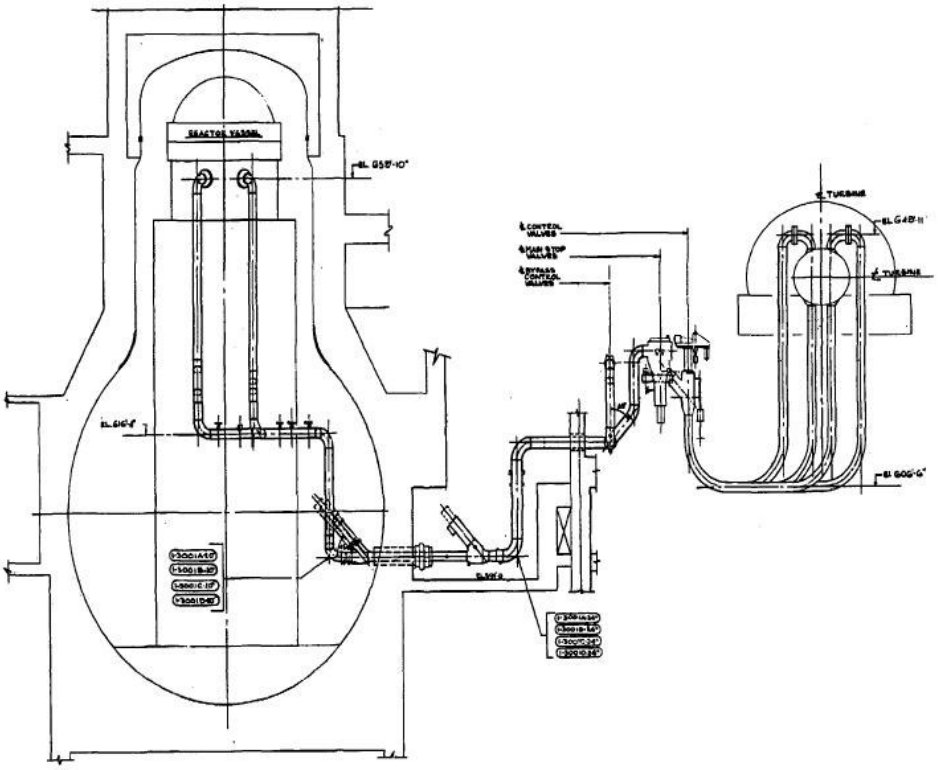
During the subsequent restart of Unit 2 on April 2, 2002, vibrations broke a drain line on one of the four main steam pipes. Workers knew the main steam pipes were vibrating abnormally at the Experimental Power Uprate conditions because insulation and – of all things – vibration monitors had shaken loose and fallen from the pipes.[5] Workers fixed the broken line – not its cause – and restarted Unit 2 to resume the Experiment.

The main steam pipes signaled trouble again on June 7, 2002. With Unit 2 steadily operating at Experimental Power Uprate conditions, the indicated flow in main steam line 'A' suddenly increased from 2.95 to 3.05 million pounds per hour while the indicated flows in the remaining three lines decreased. The plant's owner, the reactor's manufacturer, and the site's regulator huddled about the problem.[6]

The head-scratching intensified on June 18, 2002, when the measured amount of water droplets being carried away by the steam was about four or five times the values recorded over the past three decades. When the high amount doubled over the next two days, operators suspended the Experimental Power Uprate by reducing Unit 2's output below the original licensed level. But the damage had already been done. Operators shut down Unit 2 on July 11, 2002, for repairs.[7]



Workers soon spotted a gaping hole in the steam dryer. Metal fragments from the hole were later found in a flow instrument for one of the main steam lines and on the inlet screen for a main turbine stop valve. Thus, at least one fragment from the cracked, broken steam dryer sitting above the reactor core was carried by steam out of the reactor vessel, past both of the main steam isolation valves, out of the primary containment, out of the secondary containment, to the stop valve in the turbine building.

According to Exelon, the owner of the Quad Cities reactors:

> *The root cause of the steam dryer failure was determined to be a lack of industry experience and knowledge of flow-induced vibration dryer failures. The dryer failed as a result of fatigue caused by flow-induced vibrations created by higher steam flows due to Extended Power Update conditions.*[8]

Hence, the Experiment fills in gaps in the nuclear industry's knowledge. The nuclear industry did not know what to expect or what might happen, so Exelon cranked up Quad Cities Unit 2 to find out. But the resulting steam dryer snap, crackle, and pop in 2002 only schooled the industry on how to band-aid that problem, not how to prevent it.

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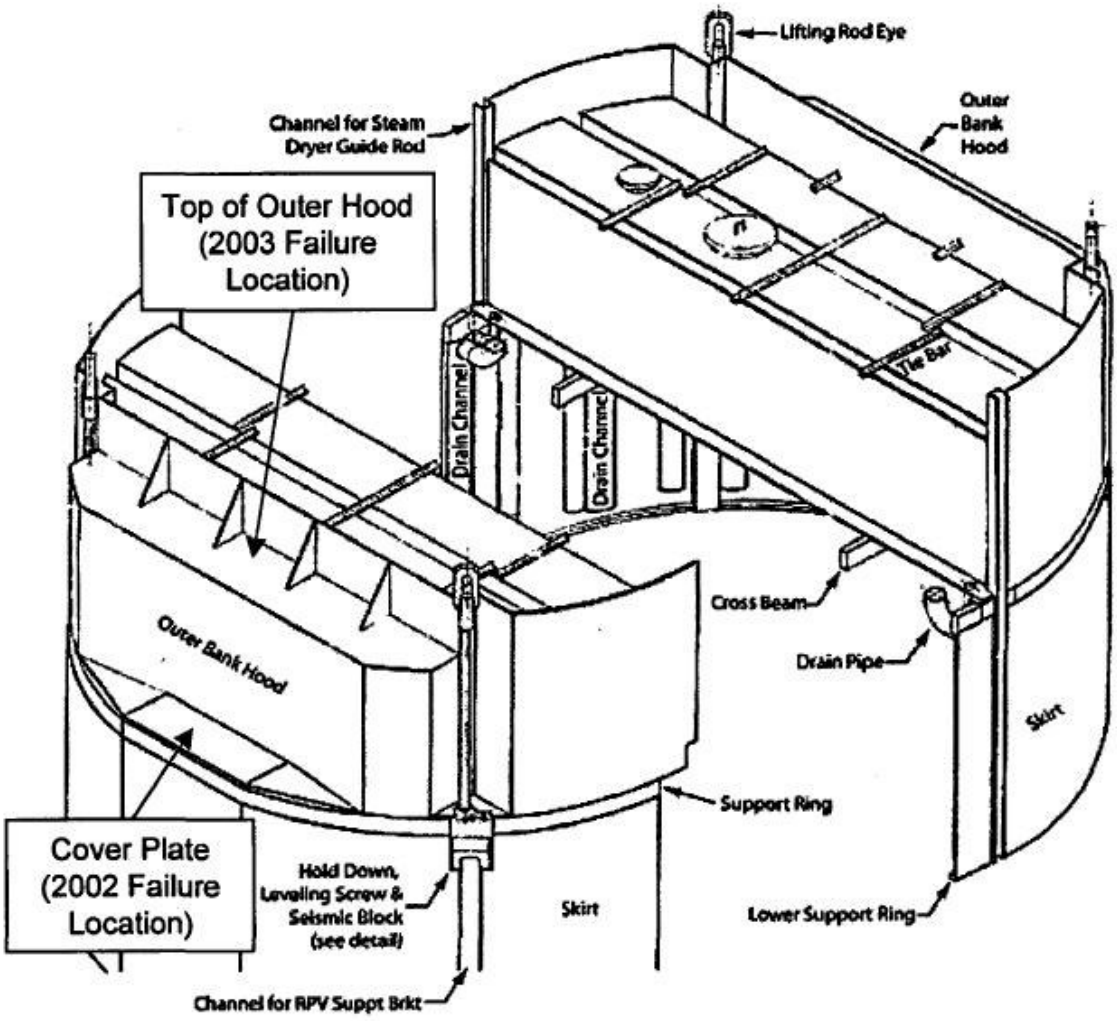
After repairing the steam dryer by replacing the damaged plate and adding braces, workers restarted Unit 2 on July 21, 2002, and resumed the Experiment.

The next phase of the Experiment began on May 6, 2003, when the measured amount of water droplets in the steam again significantly exceeded the normal value. On May 28, 2003, operators suspended the Experiment by reducing Unit 2's power output below the original licensed level. Two weeks later, Unit 2 was shut down for another round of steam dryer repairs.[9]

It was again child's play to spot the damage – a crack in the steam dryer ¾ inch wide and merely 9 feet long.



The damage was not in the exact same location as in 2002, but Exelon recycled the same excuse nonetheless:

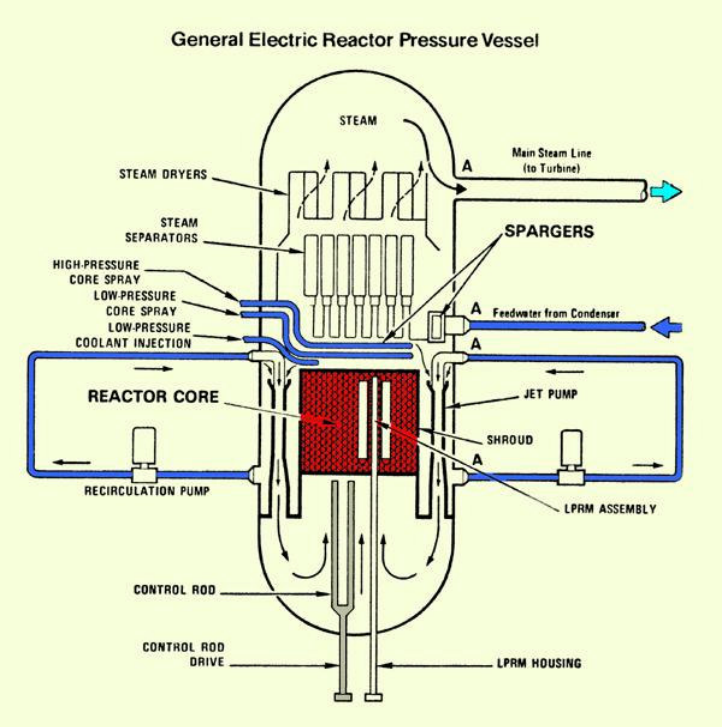
> *The root cause of the steam dryer failure was determined to be a lack of industry experience and knowledge of flow-induced vibration dryer failures. The dryer failed as a result of fatigue caused by flow-induced vibrations created by higher steam flows due to EPU conditions.*[10]

In other words, not enough knowledge was gained from the steam dryer shaking itself apart in 2000 to prevent it from happening again in 2003. Not enough data? No problem, there are more BWRs to include in the Experiment. Enter Quad Cities Unit 1.

On October 26, 2003, the indicated flow in main steam line 'D' suddenly increased by 0.5 million pounds per hour while the indicated flows in the remaining three lines decreased.* Within days, the amount of water droplets in the steam was measured at significantly higher than the usual value. Operators suspended the Experiment on November 3, 2003, by reducing Unit 1's power output below the original licensed level. Unit 1 was shut down on November 12, 2003, for repairs to the steam dryer. That same month, workers discovered cracks in the Dresden Unit 2 (another Exelon BWR) steam dryer following a single operating cycle at the Experimental Power Update conditions.[11]

When workers entered the Quad Cities Unit 1 containment for the now well-rehearsed repairs to the steam dryer, they found a new problem. The vent line broke off the pilot valve for one of the electromatic relief valves. Technicians later concluded that vibrations broke the vent line, which prevented the relief valve from opening as required in event of an accident. Although its operating license only allowed Unit 1 to operate for 14 days with a broken relief valve, the reactor had operated for nearly 110 days in that degraded condition. [12]

The Unit 1 steam dryer had a half-inch thick piece of the outer hood bank measuring about 6 ½ inches by 9 inches missing. Workers could not locate the missing piece(s), but they did find evidence of its journey. One of the two large pumps that recirculates cooling water through the reactor core had scratch marks on its impeller. The pump's impeller had been replaced in 2002 so the damage was recent.



Workers restarted Unit 1 after repairing the steam dryer and abandoning the search for its missing pieces. Exelon guessed the steam dryer piece, or a fragment thereof, passed through the recirculation pump and now resides inside the lower curved dome of the reactor vessel.

On March 18, 2004, the NRC teleconferenced with Exelon about recent inspections of the steam dryer during the spring refueling outage on Unit 2. The Experiment continues to add to the nuclear industry's knowledge of how steam dryers break while remaining coy about how to stop the damage:

- Cracks formed in some of the plates added during the 2003 repairs
- Cracks formed in a weld where a stiffener plate was added
- A one-inch crack formed in a steam dryer seam

* This steam flow redistribution occurs because the hole(s) in the broken steam dryer allows a "short cut" for steam to the nearest steam pipe.

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Exelon may have tired of the Experiment. They plan to replace the steam dryers at Quad Cities as soon as practical. For Unit 1, that means the refueling outage scheduled for March 2005. For Unit 2, that means the refueling outage scheduled for spring 2006.[13]

In Exelon's own words:

> ***The dryer is a non-safety related component whose only safety function is to remain intact such that no loose part will prevent a safety related component from performing its function***.[14]

The steam dryer has no moving parts. It is a bunch of metal plates, some with holes drilled through them, welded together. The only thing one has to do is keep it intact. The Experimental Power Uprate failed three times against this fairly simple success criterion at Quad Cities in less than two years.

The NRC informed Exelon that:

> *the NRC staff noted that the licensee's resolution of the potential adverse flow effects from EPU operation at Quad Cities and Dresden continues to rely primarily on questionable analyses*.[15]

Lack of knowledge caused the problems. Questionable analyses hinder their resolution. Yet the NRC allows BWRs in Illinois, Iowa, and North Carolina to operate at Experimental Power Uprate conditions justified by the ill-informed, questionable analyses. The NRC's mission is to protect public health and safety. The BWR Power Uprate Experiment conflicts with that mission.

For the NRC to allow BWRs to continue operating at Experimental Power Update conditions is to naively assume that the only adverse consequences from the incomplete knowledge and questionable analyses have – very politely – revealed themselves in the form of Swiss-cheese steam dryers and vibration monitors lying on the floor. What about emergency systems also incapacitated at the Experimental Power Uprate conditions but still undetected? We won't know until someday when these standby emergency systems are called upon during an accident and fail to respond. That lesson will come with a very high, and totally unnecessary, price tag.

Repeatedly told that the nuclear industry doesn't have enough knowledge about Experimental Power Update conditions, the NRC is shirking its responsibility to protect the public by allowing clueless plant owners to crank up BWRs to see what happens.

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