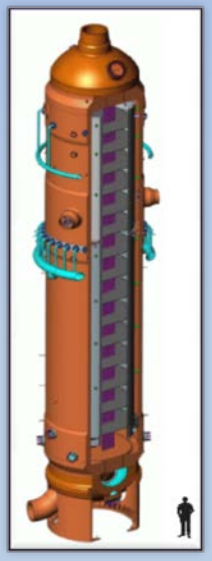

Steam Generator

Three Mile Island's Steam Generator Safety Is Suspect During Reactor Transient Conditions

TMI Alert Petitions the Nuclear Regulatory Commission to Take Enforcement Action

Contact: Scott D. Portzline
sdportzline1@verizon.net

March 11, 2019

TMI Unit #1

- There is a risky and dangerous unanalyzed safety condition involving the steam generators.
- The steam generators could fail and stop removing heat from the reactor.
- The problematic behavior is not predictable by standard engineering analyses.
- Excessive fluttering of the steam tubes could occur when the reactor systems are challenged.
- The steam generators could self-destruct.
- Result in a "containment bypass accident."
- A large amount of radiation is released without any time for an evacuation.

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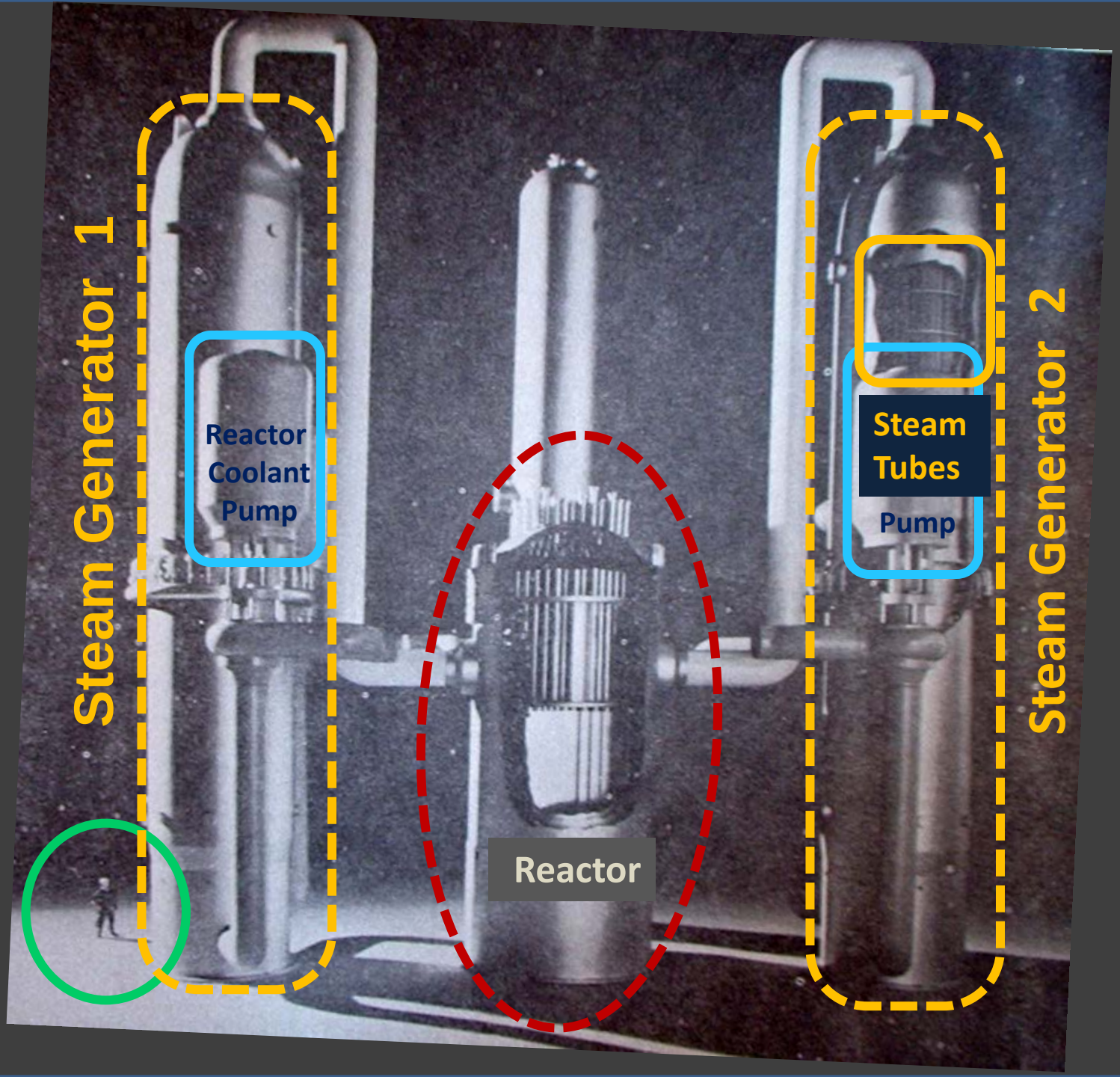
Protecting People and the Environment

"Consequential steam generator tube ruptures are potentially risk-significant events because thermally induced SG tube failures caused by hot gases from a damaged reactor core can result in a

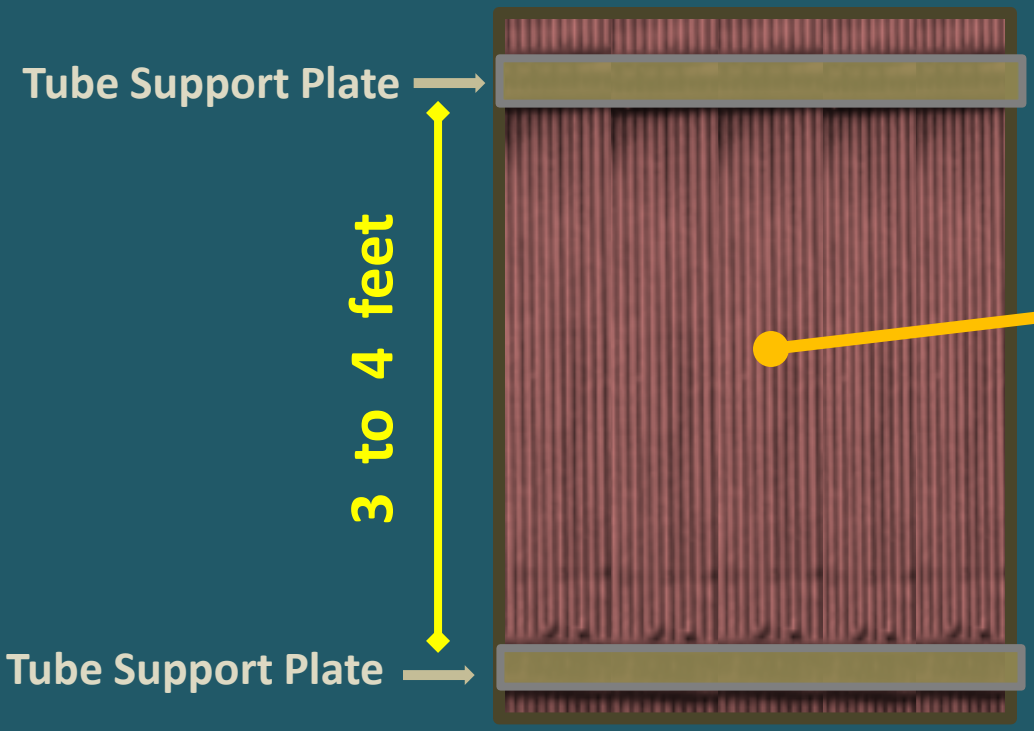
containment bypass event and a large release of fission products to the environment."

source: Nuclear Regulatory Commission
NUREG-2195, May 2018

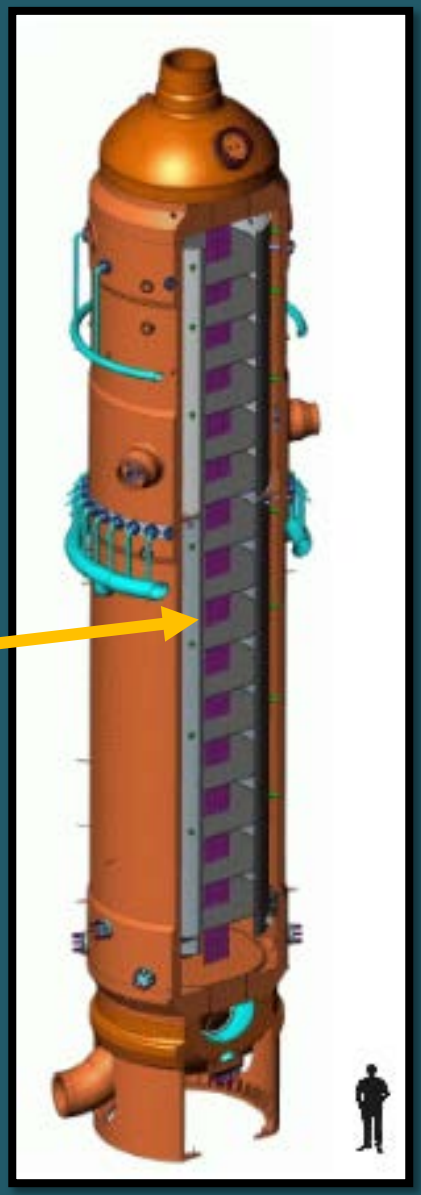
Video: Fluttering of the Steam Tubes


Steam Generator 1
Reactor Coolant Pump
Reactor
Steam Tubes
Pump
Steam Generator 2

Each Steam Generator is 72 feet tall and packed with 15,597 vertically oriented Steam Tubes which are 56 feet in length.



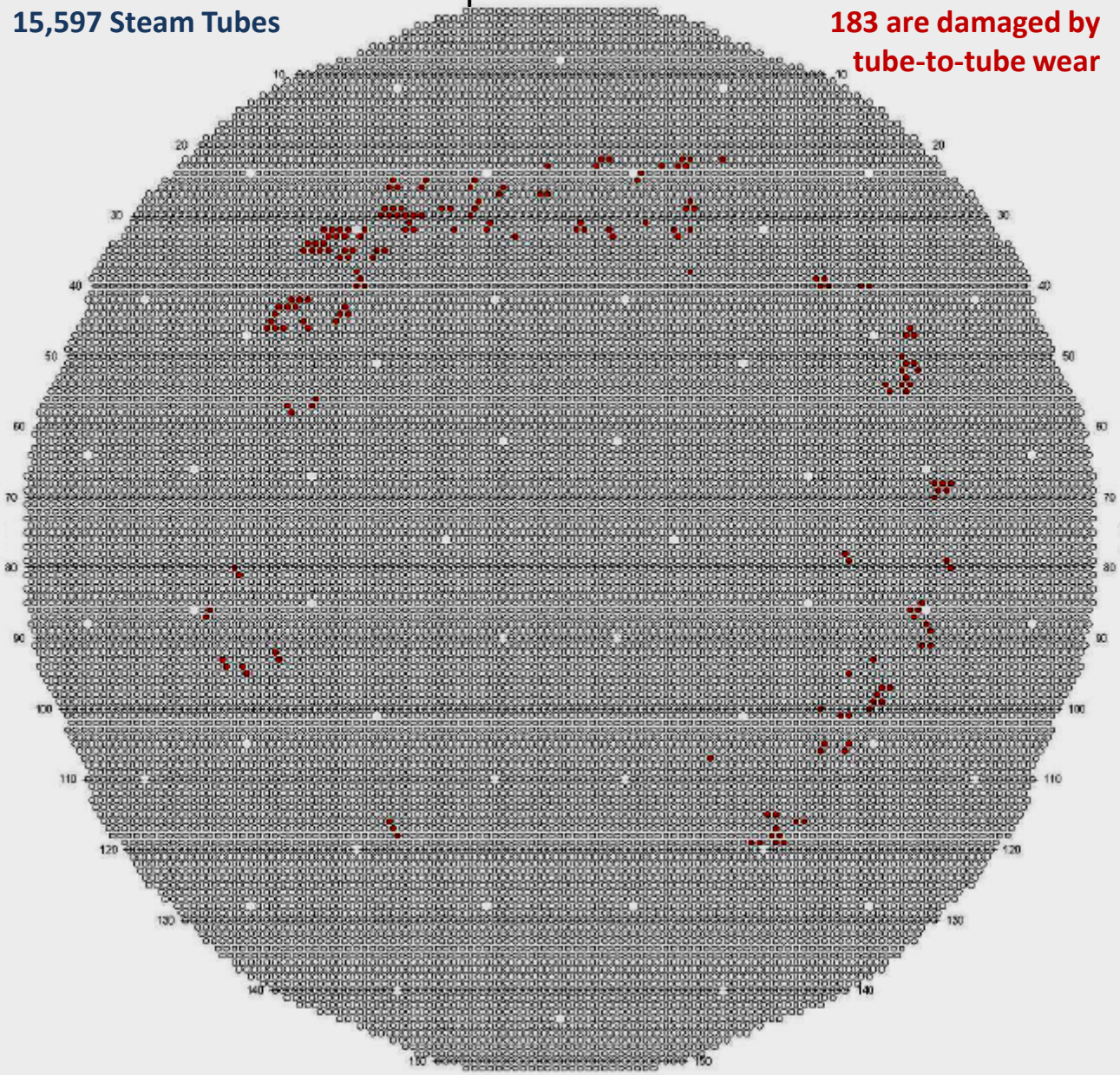
A section of Steam Tubes



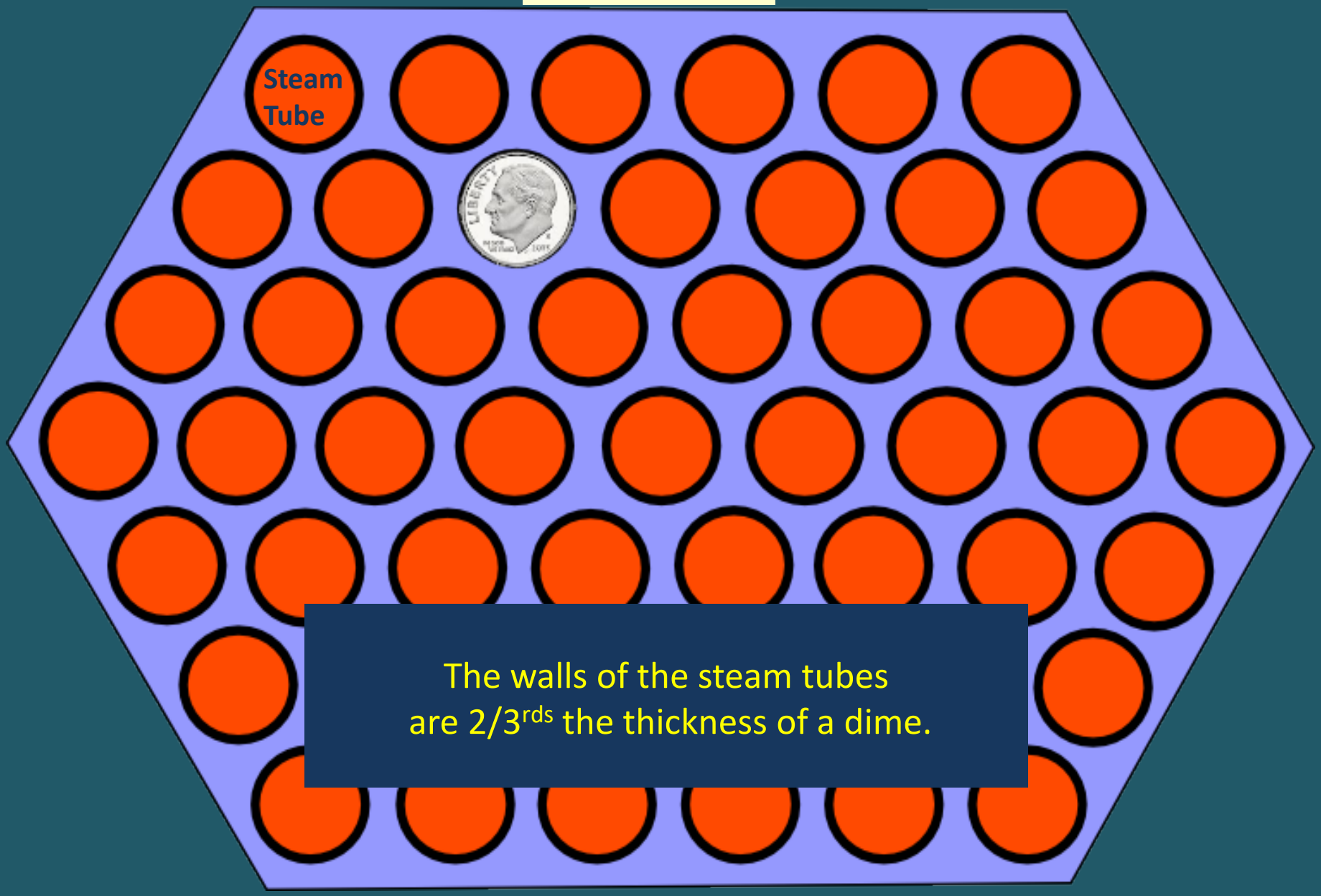
Top view SG “B”

15,597 Steam Tubes

183 are damaged by tube-to-tube wear

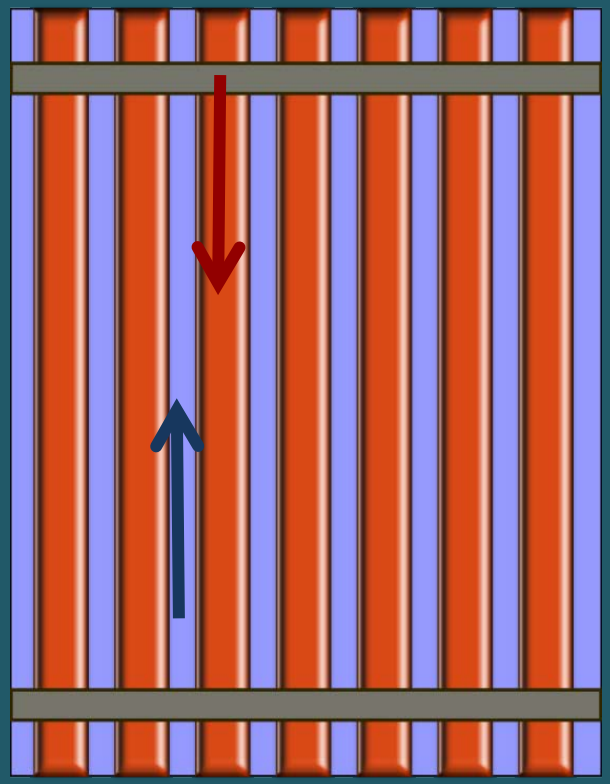


Top view

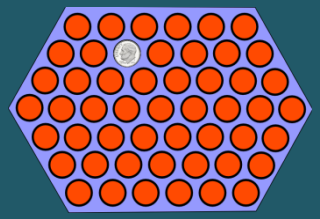


The walls of the steam tubes
are 2/3^{rds} the thickness of a dime.

Side view



Top view

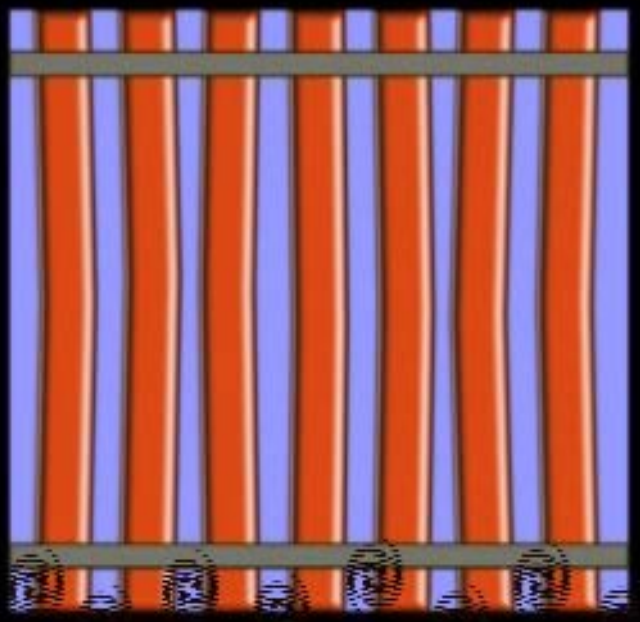


Think of a steam generator as a heat exchanger. The steam tubes (in red) conveying the reactor coolant are separated by gaps through which a separate supply of water is pumped in an upward direction. This water is used to create steam.

This is how the heat is exchanged from the reactor coolant to the water used for the steam.

Steam generators are the primary method of cooling a reactor and as such are a very important safety component.

Video: Turbulence Is Causing The Fluttering



Feedback Mechanism

"The more you have motion [of the steam tubes], the more you have hydraulic excitation. The more you have hydraulic excitation, the more you've got motion."

Principal Research Engineer

Atomic Energy of Canada

source: Nuclear Regulatory Commission briefing transcript, Feb. 7, 2013

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Not Reviewed by the NRC

"For the steam generators, the thermal hydraulic conditions on the secondary side are not something that's within our standard review plan."

Nuclear Reactor Regulations
Reactor Systems Branch Chief

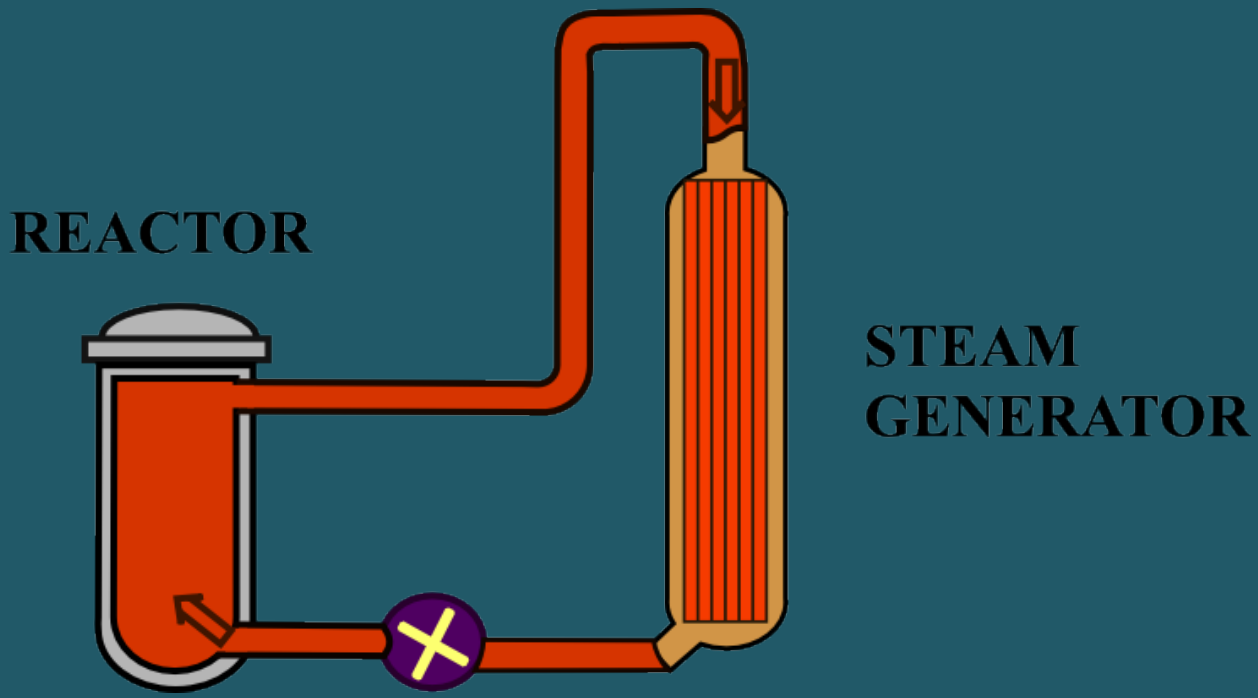
source: Nuclear Regulatory Commission briefing transcript, Feb. 7, 2013

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

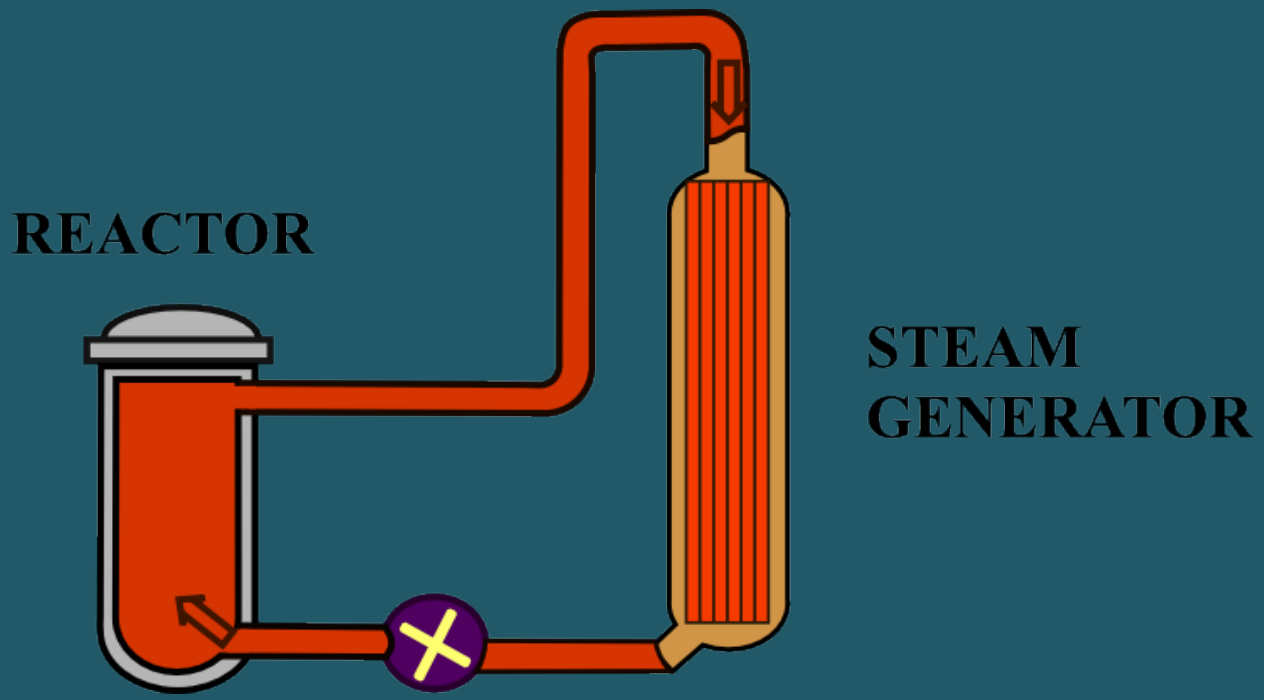
TMI Alert contends that an analysis must be performed on the steam tubes for transient conditions based on direct input from the plant system thermal hydraulic analyses.

Because TMI Unit #1 has already experienced unexpected steam tube damage as the result of fluttering, **there appears to be a significant increased risk of an accident and a significant increase in the consequences of such an accident.**

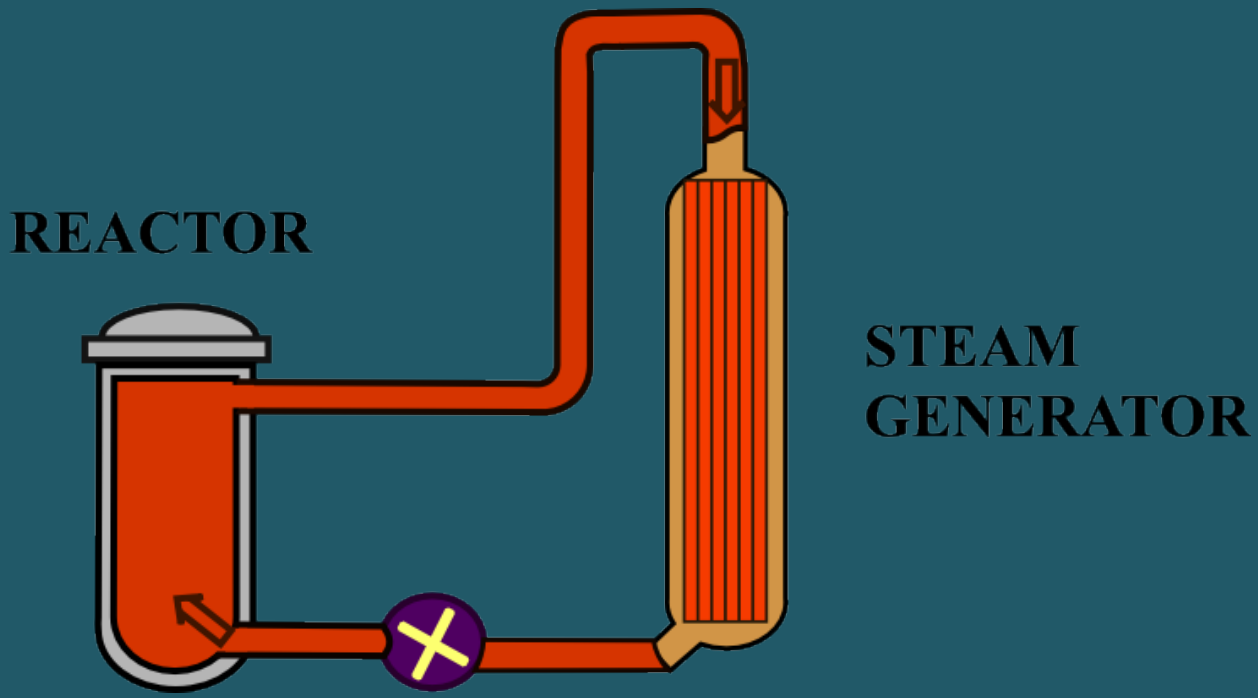
The NRC considers a steam tube rupture an “accident” because it leaks reactor coolant into the steam supply.



Steam tubes are an integral part of the reactor coolant pressure boundary and as such, are relied upon to maintain the reactor system's pressure and coolant inventory.



The rupture of multiple steam tubes results in a large break loss-of-coolant accident. Steam tube ruptures can be the **cause** of a severe accident and radiological release.

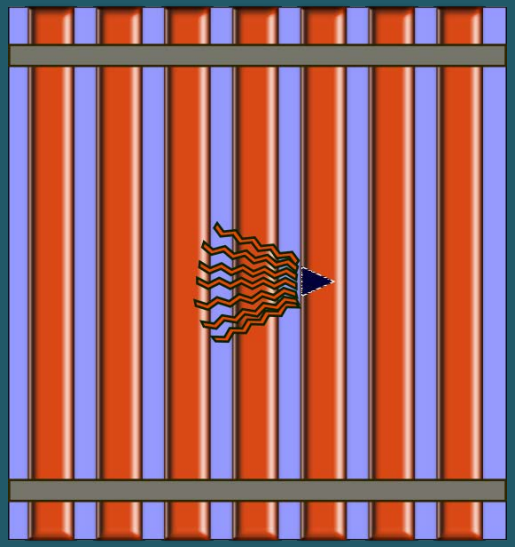


- "These [spontaneous] ruptures have caused complex plant transients which have not always been easy for the reactor operators to control.

- A continuing issue has been - exactly what constitutes an appropriate and timely inspection and which degraded tubes are still fit for service.

- The most widely used inspection equipment is not able to detect and size all the degradation of concern."

source: Idaho National Laboratory
NUREG-6365, April 1996



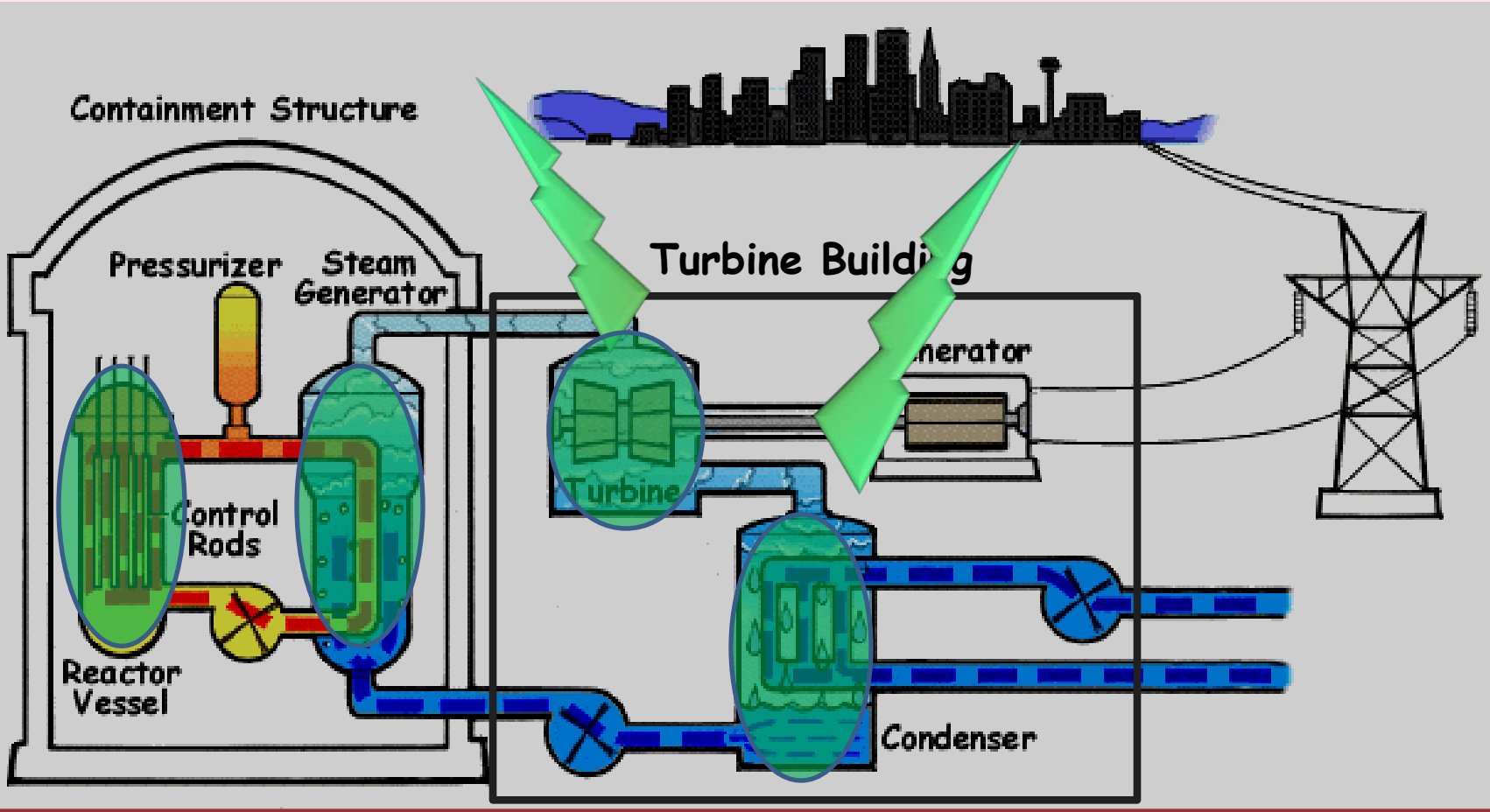
Reactor coolant jetting
from a ruptured steam tube.

The rupture of the steam tubes “can result in a containment bypass event and a large release of fission products to the environment.”

NUREG-2195

This scenario is called a “containment bypass accident” because a pathway is created for radiation to escape out of the containment building and into the environment.

Containment Bypass Accident

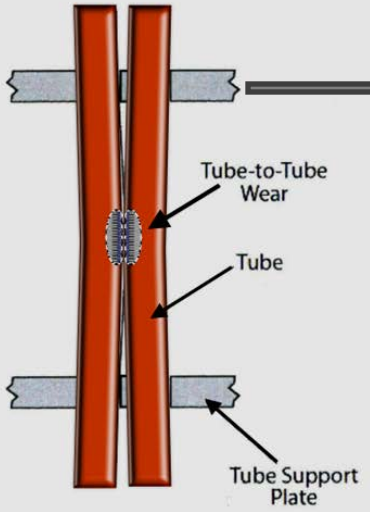


Three Mile Island Unit #1

Tube-to-Tube Wear

bowing + fluttering

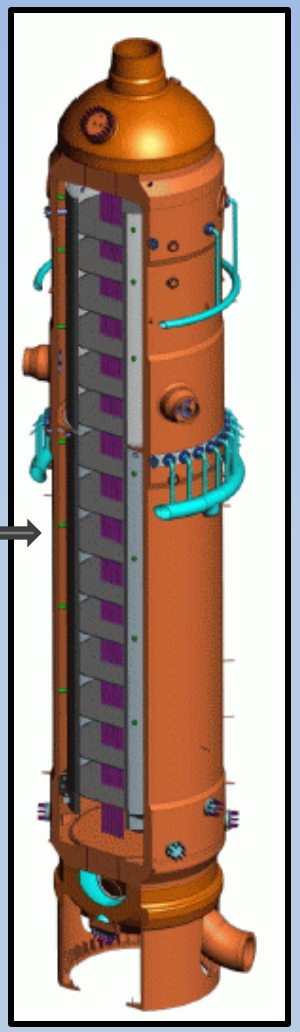
Tube-to-Tube Wear
Steam Generators



23

A total of 257 steam tubes showed signs of tube-to-tube wear.

A few were approximately 20% through the tube wall.



Steam Generator

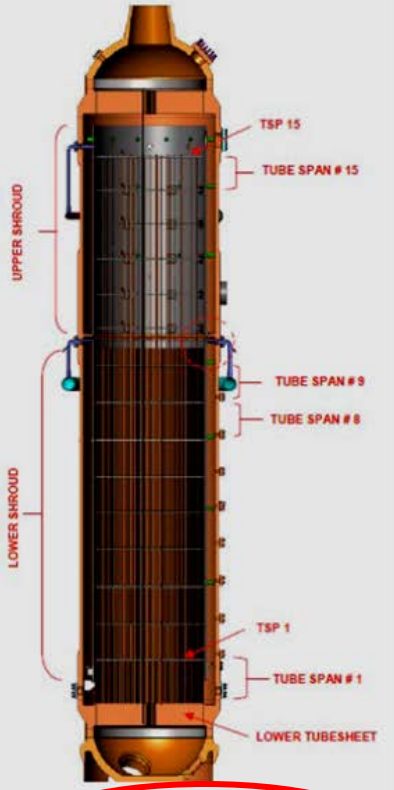
Image source: Nuclear Regulatory Commission briefing 2/7/2013 - Steam Generator Tube Degradation

Fluttering

Root Cause Findings

Two basic causes of the tube-to-tube wear:

1. Compressive loads resulting in bowing at the 9th span causing tube-to-tube contact.
2. Excitation forces created by either random turbulence or flutter.



Exelon Generation

Fluttering

AREVA Root Cause Findings

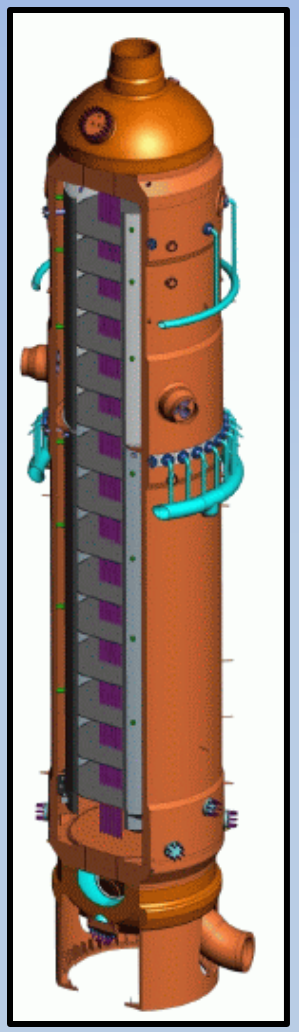
Root Cause determined to be a combination of 4 Contributing Causes:

1. Margin to buckling was non conservative in design. → Reduced margin to bowing
2. EOTSG shell cooler than design value. → Higher compressive loads
3. Tube preload less tensile than value in design analysis → Higher compressive loads
4. Lateral loads/accelerations are sufficient to cause tube-to-tube wear. → Excitation of compressed tubes causes wear

Exelon Generation

The damage done to TMI's steam tubes was caused by mistakes made by AREVA, the French manufacturer of the steam generators.

- DESIGN FLAW
- MANUFACTURING DEFECT
- OVERLY AGGRESSIVE DESIGN



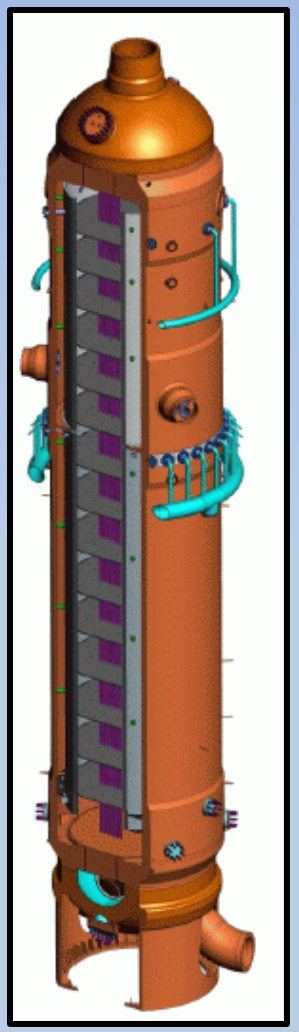
Steam Generator

Root Cause

1. **Design Flaw**

thermal expansion rates

When operating, the steam generator shell stays cooler than expected. The steam tubes expand at a greater rate than the shell. The result is that the tubes experience higher compressive loads from end-to-end than planned. This results in bowing of the tubes.



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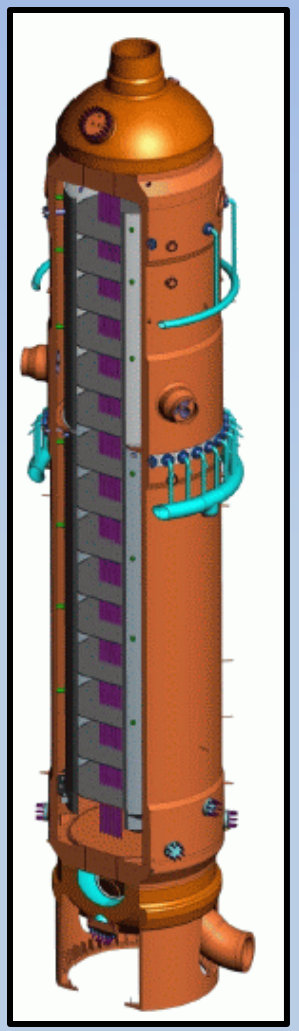
“During a transient condition the thermal expansion can be significant.”

Steam Generator Integrity Assessment Guidelines Revision 3, Electric Power Research Institute

Root Cause

2. Manufacturing Defect

The steam generators were not constructed as designed. Specifically, the preload tensile value of the steam tubes was less than called for by the design specification. The result is the steam tubes experience a higher compressive load than planned.



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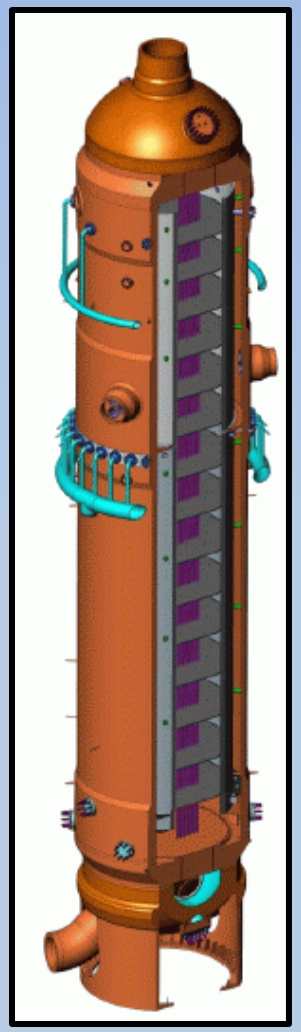
Root Cause

3. Overly Aggressive Design

- The margin to steam tube bowing was not conservative.
- The steam tube walls are thinner than the previous design.
- The steam tubes are smaller in diameter and packed together tighter than in previous designs. The gap between the tubes is only 1/8 inch when the reactor is operating at normal temperatures.



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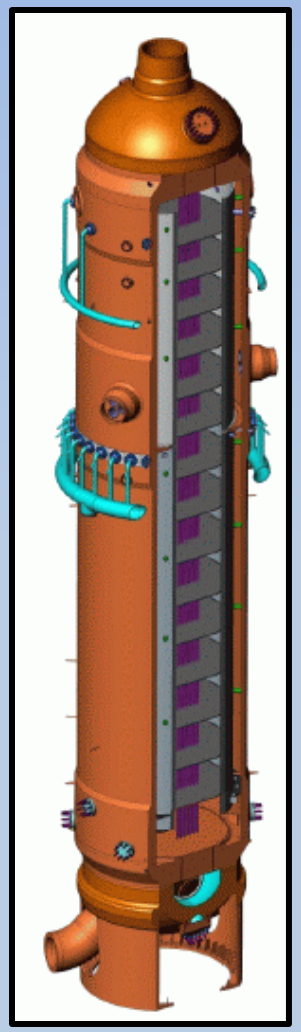

Steam Generator

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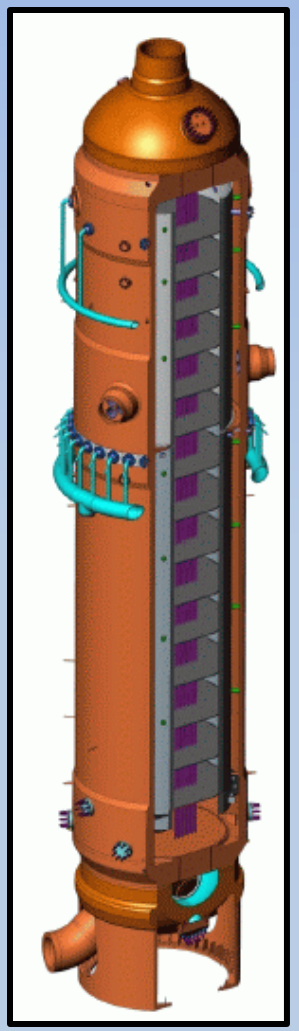
Therefore, these three specifications, produced by intentional design, make any tube-to-tube wear of even greater concern regarding steam tube ruptures.



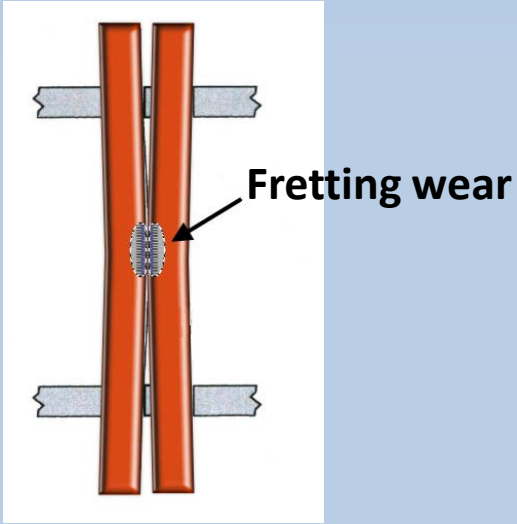
Steam Generator

Alloy 690

- The new metal Alloy 690 used to manufacture the steam tubes is less resistant to stress corrosion cracking, but it frets, pits and wears faster that the metal used in previous designs (Alloy 600).
- As time goes by there is a greater risk of tube cracking and rupture.

"Through these experiments, it is found that the fretting fatigue strength decreased about 43% compared to the plain fatigue strength…. oblique micro-cracks are initiated at an earlier stage."

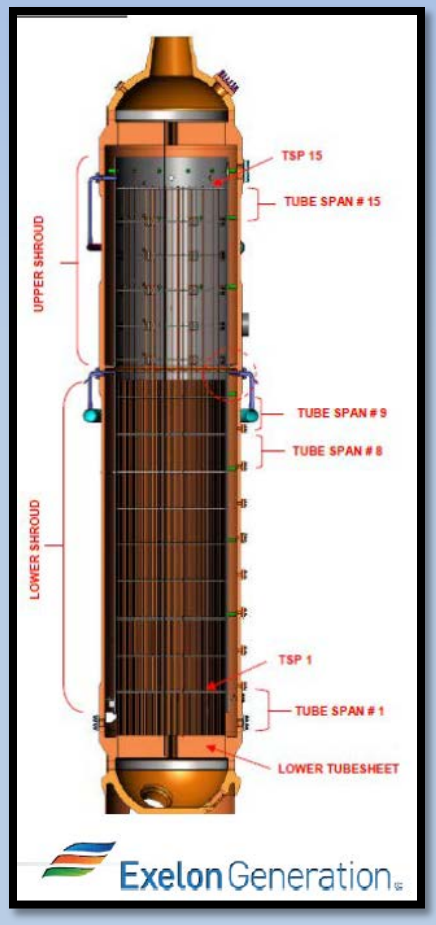
source: A Study on Fretting Behavior in Room Temperature for Inconel Alloy 690



Under reactor transient conditions, the steam generators could self-destruct due to fluttering steam tubes.

At TMI Unit #1 steam tube flutter is created by the turbulent and chaotic flow of the secondary system water between the tubes (thermal hydraulic conditions).

Under higher temperatures, the energy of the flutter could impart severe damage to many steam tubes, including ones that were not effected during normal operating temperatures. This represents a hidden consequence of the new design.



Feedback Mechanism

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Principal Research Engineer

Atomic Energy of Canada

source: Nuclear Regulatory Commission briefing transcript, Feb. 7, 2013

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

TMI Alert expects these conditions and behaviors to be analyzed under reactor transient conditions:

- Greater number of tubes bowing
- Greater severity of the bowing
- Changes in geometry of the SG due to narrowing of the tube gaps
- Greater velocity of water between the tubes
- Greater amount of energy of the flutter (lateral accelerations)
- Flutter could become more chaotic
- The effects of harmonic resonance disturbance
- Additional damage to the steam tubes at the Tube Support Plates

Th e conditions and behaviors to be
ar r transient conditions:

- ubes bowing
- he bowing
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- o the steam tubes at the Tube Support Plates

Design changes went too far!

TMI Alert asserts that the design changes of the replacement steam generators, primarily the geometry of the internal components,

- the steam tube size
- reduced gap between the steam tubes

constitutes a violation of the NRC regulation on changes.

- regulation §50.59 in 10 CFR "Changes, tests and experiments."

San Onofre Defective Steam Generators

- At the San Onofre Nuclear Generating Station, tube-to-tube wear caused the degradation of their replacement steam generators.
- A design error resulted in the actual steam generators having more severe thermal-hydraulic conditions than expected, which contributed, along with other factors, to the rapid steam tube wall degradation.
- The steam tube walls at TMI are 20% thinner than at San Onofre.

Incremental changes

Nuclear plants are allowed to make small changes to their reactor components and safety systems without amending their license. However, a series of small changes in one component can add up to a risky and dangerous defect. As the conservative margin for safety and reliability is decreased in the pursuit of efficiency, the line delineating safe from unsafe designs grows ever closer. At some point, safety systems will not be able to perform their functions under stressful loads or conditions.

Some of these defects can be hidden from detection under normal testing and analysis; even for the analytical methods approved by the industry.