Risk Management and Risk Perceptions

May 3, 2004

Elements of Risk Management

- Risk assessment
  - What is the probability of an accident? What are the likely consequences?
- Risk management
  - Prevention and mitigation
  - External regulation vs. self-regulation
- Risk communication
  - Informing the public about risk, and responding to expressed concerns

Probabilistic Risk Assessment (PRA)

- A methodology for answering three questions:
  - What can go wrong (accident scenario)?
  - How likely is this to occur (probability, frequency)?
  - What will be the outcome (consequences)?

Definition of Risk:

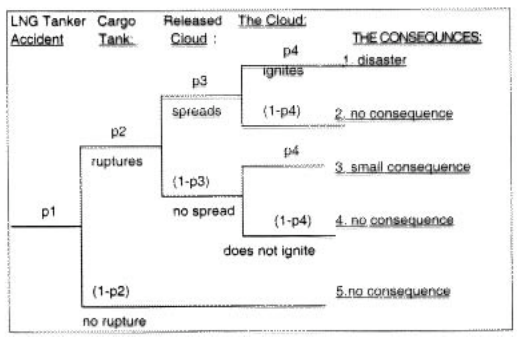
Risk (consequences/unit time) = frequency (event/unit time) x magnitude (consequence/event)

- Two key tools:
  - Event tree analysis
  - Fault tree analysis

PRA: Event Tree Analysis

- "An analytical technique for systematically identifying potential outcomes of a known initiating event."
  - Select candidate initiating event
  - Using inductive reasoning, construct sequences of subsequent events or scenarios that end in a 'damage state'
  - Estimate probability of each event on the pathway leading to the accident

LNG Accident Event Tree

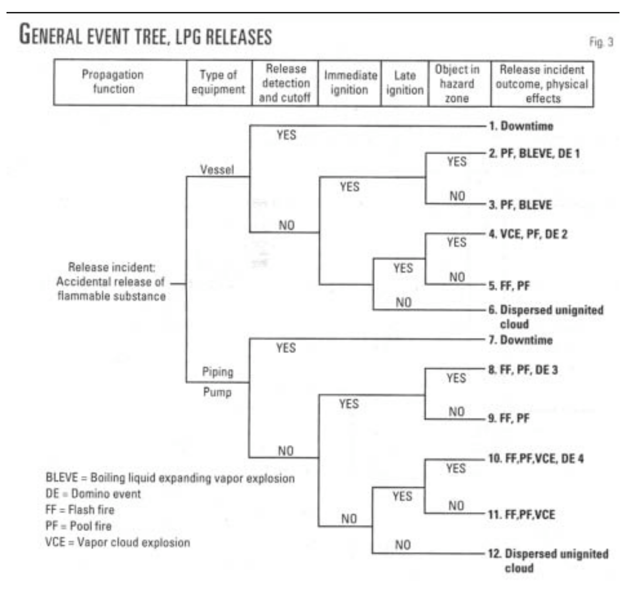


Probability of disaster = $p_1 \times p_2 \times p_3 \times p_4$

Sum of probabilities of all outcomes = p_1

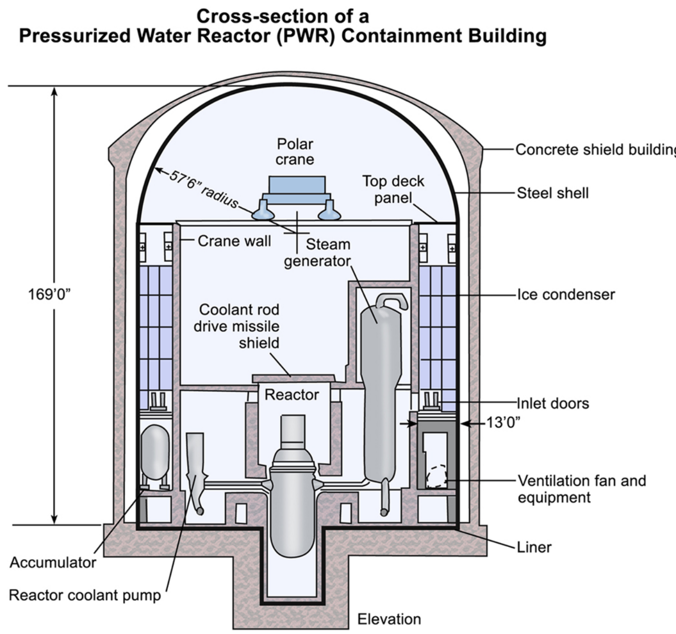
Probability of no consequence given an accident = $p_2(1- p_4) + (1- p_2)$

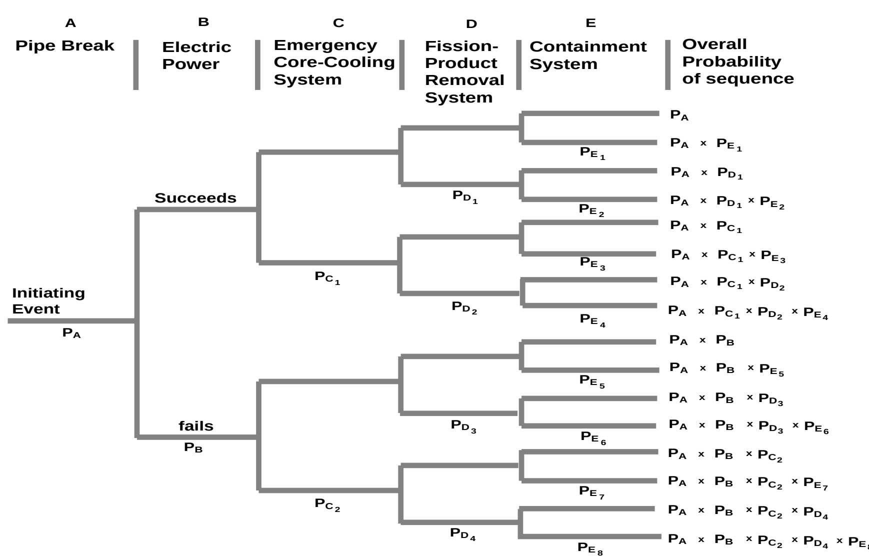
Probability of a small consequence given an accident = $p_2 \times (1- p_3) \times p_4$



Source: Adam Markwoski, Oil and Gas Journal, 9 September 2002

Light Water Reactor Safety Philosophy: Defense-in-depth





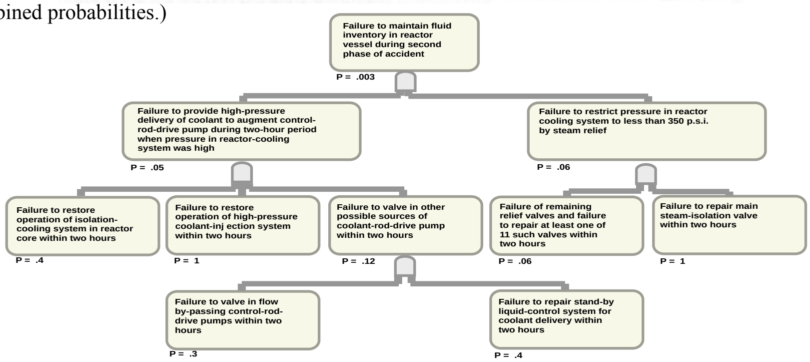
Source: Reactor Safety Study WASH-1400 analysis of the 1975 Brown's Ferry accident After Lewis, 1980.

PRA -- Fault Tree Analysis

1) “An analytical technique whereby an undesired state of the system is specified, and thesystem is then analyzed in the context of its environment and operation to find allcredible ways in which the undesired event can occur.

2) ”Use deductive reasoning to think of all possible ways in which the ‘top event’ couldhave occurred.

3) Then estimate the probabilities (relying on empirical data for the most basic events,and algebra to get combined probabilities.)



Source: Reactor Safety Study WASH-1400 analysis of the 1975 Brown's Ferry accident After Lewis, 1980.

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Assessing PRA

- The value of PRA:
  - Forces systematic attention to accident scenarios
  - Structures debate about differences in scenario definition or parameter estimation
  - Identifies ‘most bang for the buck’ components, subsystems
  - Provides quantitative estimates of failure probabilities and risks
- Problems:
  - Is the list of initiating events exhaustive?
  - Can the probability of events and failures be estimated?
  - Common mode failures
  - Lack of alignment with public risk perceptions?

Risk perceptions

- People often express great anxiety about hazards that technical analyses indicate pose very low risks, yet are indifferent to other hazards about which experts are much more concerned.
- The experts measure risk as the product of probability and consequence.
  - No difference between activities with a high likelihood of causing a small number of fatalities and those with a low likelihood of causing a large number of fatalities.
  - If the expected number of fatalities is the same, the risk, according to this measure, is also the same.
  - Yet many people seem to be much more concerned about low-probability accidents with high consequences.
- How are people’s perceptions and beliefs about risks formed? What causes these perceptions to change?

"Some people say that the prime responsibility for reducing exposure of workers to dangerous substances rests with the workers themselves, and that all substances in the workplace should be clearly labeled as to their levels of danger and workers then encouraged or forced to be careful with these substances. Do you agree or disagree?"

From a survey of public attitudes towards the chemical industry

Measuring risk perceptions is not straightforward: E.g., it depends on how you ask the question.

TABLE II.1 Lethality Judgments with Four Different Response Modes (geometric mean)

Condition	Death Rate Per 100,000 Afflicted				
	Estimated Lethality Rate	Estimated Number Who Die	Estimated Survival Rate	Estimated Number Who Survive	Actual Lethality Rate
Influenza	393	6	26	511	1
Mumps	44	114	19	4	12
Asthma	155	12	14	599	33
Venereal disease	91	63	8	111	50
High blood pressure	535	89	17	538	76
Bronchitis	162	19	43	2111	85
Pregnancy	67	24	13	787	250
Diabetes	487	101	52	5666	800
Tuberculosis	852	1783	188	8520	1535
Automobile accidents	6195	3272	31	6813	2500
Strokes	11,011	4648	181	24,758	11,765
Heart attacks	13,011	3666	131	27,477	16,250
Cancer	10,889	10,475	160	21,749	37,500

NOTE: The four experimental groups were given the following instructions:
(a) Estimate lethality rate: For each 100,000 people afflicted, how many die?
(b) Estimate number who die: X people were afflicted, how many died?
(c) Estimate survival rate: For each person who died, how many were afflicted but survived?
(d) Estimate number who survive: Y people died, how many were afflicted but did not die?
Responses to (b), (c), and (d) were converted to deaths per 100,000 to facilitate comparisons.

Question. Rank the risk of death from the following activities:

TABLE 2

Ordering of Perceived Risk
for 30 Activities and Technologies*

	Group 1 LOWV	Group 2 College Students	Group 3 Active Club Members	Group 4 Experts	Tech. [illegible]
Nuclear power	1	1	8	20	20
Motor vehicles	2	5	3	1	3
Handguns	3	2	1	4	4
Smoking	4	3	4	2	1
Motorcycles	5	6	2	6	6
Alcoholic beverages	6	7	5	3	2
General (private) aviation	7	15	11	12	11
Police work	8	8	7	17	17
Pesticides	9	4	15	8	28
Surgery	10	11	9	5	8
Fire fighting	11	10	6	18	16
Large construction	12	14	13	13	12
Hunting	13	18	10	23	14
Spray cans	14	13	23	26	30
Mountain climbing	15	22	12	29	21
Bicycles	16	24	14	15	13
Commercial aviation	17	16	18	16	19
Electric power	18	19	19	9	5
Swimming	19	30	17	10	7
Contraceptives	20	9	22	11	15
Skiing	21	25	16	30	24
X rays	22	17	24	7	9
High school & college football	23	26	21	27	23
Railroads	24	23	20	19	10
Food preservatives	25	12	28	14	27
Food coloring	26	20	30	21	26
Power mowers	27	28	25	28	22
Prescription antibiotics	28	21	26	24	29
Home appliances	29	27	27	22	15
Vaccinations	30	29	29	25	25

*The ordering is based on the geometric mean risk ratings within each group. Rank 1 represents the most risky activity or technology.

Source: Paul Slovic, Baruch Fischoff and Sarah Lichtenstein, "Facts and Fears: Understanding Perceived Risk", in R. Schwing and W.A> Albers, Jr (eds), Societal Risk Assessment: How Safe is Safe Enough?, New York, Plenum (1980): 181-214

Two possible explanations for the divergence between lay people’s perceptions of risk and the actual fatality data:

1. Members of the public base their judgments of risk on factors other than expectations of annual fatalities

2. Public risk perceptions are based on expectations of fatalities, but these expectations are inaccurate.

Question: How many people are likely to die in a typical year from these activities?

Fatality Estimates and Disaster Multipliers
for 30 Activities and Technologies

Activity or Technology	Techincal Fatality Estimates	Geometric Mean Fatality Estimates Average Year	
		LOWV	Students
1. Smoking	150,000	6,900	2,400
2. Alcoholic beverages	100,000	12,000	2,600
3. Motor vehicles	50,000	28,000	10,500
4. Handguns	17,000	3,000	1,900
5. Electric power	14,000	660	500
6. Motorcycles	3,000	1,600	1,600
7. Swimming	3,000	930	370
8. Surgery	2,800	2,500	900
9. X rays	2,300	90	40
10. Railroads	1,950	190	210
11. General (private) aviation	1,300	550	650
12. Large construction	1,000	400	370
13. Bicycles	1,000	910	420
14. Hunting	800	380	410
15. Home appliances	200	200	240
16. Fire fighting	195	220	390
17. Police work	160	460	390
18. Contraceptives	150	180	120
19. Commercial aviation	130	280	650
20. Nuclear power	100[a]	20	27
21. Mountain climbing	30	50	70
22. Power mowers	24	40	33
23. High school & college football	23	39	40
24. Skiing	18	55	72
25. Vaccinations	10	65	52
26. Food coloring	—[b]	38	33
27. Food preservatives	—[b]	61	63
28. Pesticides	—[b]	140	84
29. Prescription antibiotics	—[b]	160	290
30. Spray cans	—[b]	56	38

[a] Technical estimates for nuclear power were found to range between 16 and 600 ar geometric mean of these estimates was used here.

[b] Estimates were unavailable.

Source: Paul Slovic, Baruch Fischoff and Sarah Lichtenstein, "Facts and Fears: Understanding Perceived Risk", in R. Schwing and W.A> Albers, Jr (eds), Societal Risk Assessment: How Safe is Safe Enough?, New York, Plenum (1980): 181-214

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3. Motor vehicles	50,000	28,000	10,500	1.6	1.8
4. Handguns	17,000	3,000	1,900	2.6	2.0
5. Electric power	14,000	660	500	1.9	2.4
6. Motorcycles	3,000	1,600	1,600	1.8	1.6
7. Swimming	3,000	930	370	1.6	1.7
8. Surgery	2,800	2,500	900	1.5	1.6
9. X rays	2,300	90	40	2.7	1.6
10. Railroads	1,950	190	210	3.2	1.6
11. General (private) aviation	1,300	550	650	2.8	2.0
12. Large construction	1,000	400	370	2.1	1.4
13. Bicycles	1,000	910	420	1.8	1.4
14. Hunting	800	380	410	1.8	1.7
15. Home appliances	200	200	240	1.6	1.3
16. Fire fighting	195	220	390	2.3	2.2
17. Police work	160	460	390	2.1	1.9
18. Contraceptives	150	180	120	2.1	1.4
19. Commercial aviation	130	280	650	3.0	1.8
20. Nuclear power	100[a]	20	27	107.1	87.6
21. Mountain climbing	30	50	70	1.9	1.4
22. Power mowers	24	40	33	1.6	1.3
23. High school & college football	23	39	40	1.9	1.4
24. Skiing	18	55	72	1.9	1.6
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Other qualitative factors of risks that affect public perceptions

- Controllability
    - To what degree can people exposed to the risk avoid death by their own skill or diligence
- Immediacy
    - Is the risk of death immediate, or more likely to occur at a later time
- Severity
    - How likely is it that the consequences of an accident will be fatal
- Knowledge of risk
    - To what extent is the nature of the risk understood by those exposed to it, and by the scientific community?
- Dread
    - Is the risk one that people have learned to live with, or is it one that inspires feelings of dread?

TABLE 4

Risk Characteristics Rated by LOWV Members and Students

Voluntariness of risk

Do people face this risk voluntarily? If some of the risks are voluntarily undertaken and some are not, mark an appropriate spot towards the center of the scale.

risk assumed voluntarily	1	2	3	4	5	6	7	risk assumed involuntarily

Immediacy of effect

To what extent is the risk of death immediate — or is death likely to occur at some later time?

effect immediate	1	2	3	4	5	6	7	effect delayed

Knowledge about risk

To what extent are the risks known precisely by the persons who are exposed to those risks?

risk level known precisely	1	2	3	4	5	6	7	risk level not known

To what extent are the risks known to science?

risk level known precisely	1	2	3	4	5	6	7	risk level not known

Control over risk

If you are exposed to the risk, to what extent can you, by personal skill or diligence, avoid death?

personal risk can't be controlled	1	2	3	4	5	6	7	personal risk can be controlled

Newness

Is this risk new and novel or old and familair?

new	1	2	3	4	5	6	7	old

Chronic-catastrophic

Is this a risk that kills people one at a time (chronic risk) or a risk that kills large numbers of people at once (catastrophic risk)?

chronic	1	2	3	4	5	6	7	catastrophic

Common-dread

Is this a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for — on the level of a gut reaction?

common	1	2	3	4	5	6	7	dread

Severity of consequences

When the risk from the activity is realized in the form of a mishap or illness, how likely is it that the consequence will be fatal?

certain not to be fatal	1	2	3	4	5	6	7	certain to be fatal

Source: Paul Slovic, Baruch Fischoff and Sarah Lichtenstein, "Facts and Fears: Understanding Perceived Risk", in R. Schwing and W.A> Albers, Jr (eds), Societal Risk Assessment: How Safe is Safe Enough?, New York, Plenum (1980): 181-214

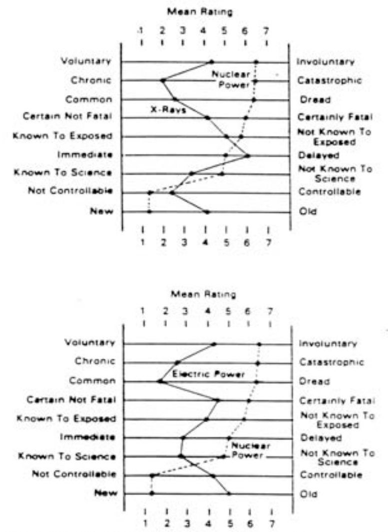


Fig. 4. Rated characteristics of risk for nuclear power and related technologies. Source: Fischhoff et al. [17].

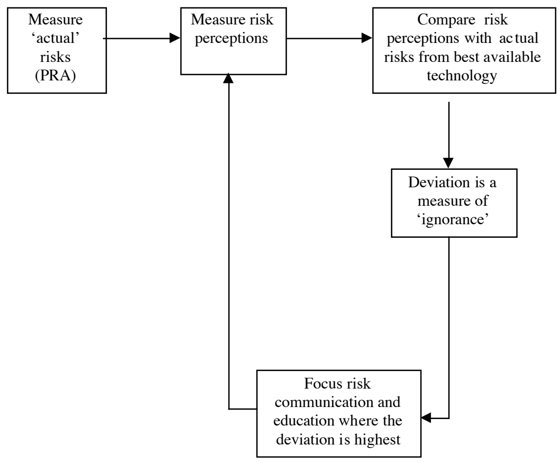
Source: Paul Slovic, Baruch Fischoff and Sarah Lichtenstein, "Facts and Fears: Understanding Perceived Risk", in R. Schwing and W.A> Albers, Jr (eds), Societal Risk Assessment: How Safe is Safe Enough?, New York, Plenum (1980): 181-214

Two Alternative Responses to Findings on Risk Perceptions

- Position 1 ('Rationalist' view): Quantitative evidence and estimates on fatalities, injuries and damage are the only basis on which to make design and technology selection decisions. Augment quantitative risk estimation methods with more effective risk communication strategies.

- Position 2 ('Populist' view): Technical choices should reflect the full spectrum of society's risk preferences, including qualitative as well as quantitative risk attributes.

An engineering-based risk communication strategy



Sunstein on ‘probability neglect’ -- rationalist view

People often focus on the goodness or badness of outcomes, and pay too little attention to the probability that a good or bad outcome will occur.

In such cases, people fall prey to ‘probability neglect’.

Probability neglect is especially large when people focus on the worst possible case or otherwise are subject to strong emotions.

When such emotions are at work, people do not give sufficient consideration to the likelihood whether the worst case will occur.

Experts are mostly concerned with the number of lives at stake, and are thus closely attuned, as ordinary people are not, to the issue of probability.

When ordinary people suffer from probability neglect, they are exhibiting behavior that is not fully rational. It is not true to say that they have a kind of ‘richer rationality’, that is superior to that of the experts .

-- Cass Sunstein, “Probability Neglect: Emotions, Worst Cases, and Law”, U.. Pa L. Rev.

But still, what should the government do?

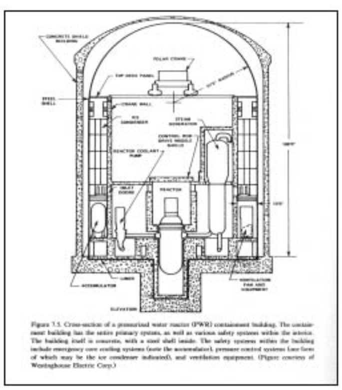
Example: Suppose that people are afraid of arsenic in drinking water, and that they demand steps to provide assurance that arsenic levels won't be hazardous. Even if the risks at existing levels are infinitesimal, should the government refuse to do what people want it to do? What if the costs of not acting – the costs of continuing public fear – are very high? Shouldn't the government act to reduce public fear?

"At first glance, the government should not respond if the public is demanding attention to a statistically miniscule risk, and doing so simply because people are visualizing the worst that can happen. The best response is information and education. But public fear is itself an independent concern, and it can represent a high cost in itself and lead to serious associated costs, often in the form of 'ripple effects'. If public fear cannot be alleviated without risk reduction, then government should engage in risk reduction, at least if the relevant steps are justified by an assessment of costs and benefits."

-- Cass Sunstein,

The future of nuclear power: Passive safety vs. defense-in-depth

Light water reactors: defense-in-depth



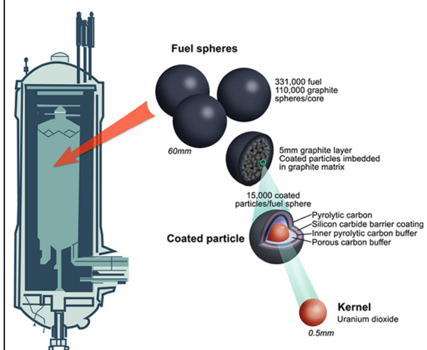
PRA result

Frequency of core-damage accidents:

10^{-4} per year

i.e., 1 in 10,000 reactor -years of LWR operation

Helium-cooled, graphite-moderated, modular pebble-bed reactor



- Hundreds of thousands of tennis-ball-sized graphite pebbles
- Each pebble contains thousands of uranium-oxide particles, ~0.5 mm in diameter, coated with layers of carbon and silicon carbide to prevent fission product escape
- Ordinarily, core is cooled by high pressure helium gas, which either drives gas turbine directly or generates steam to drive steam turbine
- Loss of coolant accident: helium has v. low heat capacity, so all heat initially absorbed by graphite pebbles.
- Pebbles are thermally stable and retain integrity even at very high temperatures.
- Even in worst-case scenario -- withdrawal of control rods, depressurization of core, and complete loss of coolant, fuel remains intact with no requirement for active cooling (passive heat removal by thermal conduction and radiation sufficient to remove decay heat)

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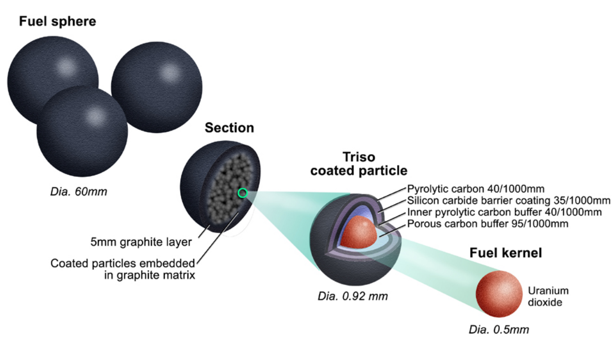
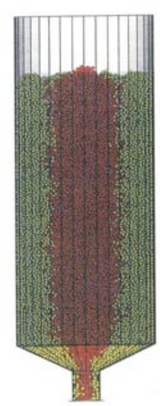
PBMR Design Certification





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How much is 'passive safety' worth?

- Reduced need for engineered emergency safety systems
- No need for massive containment? (Aircraft/missile strikes)
- Safety more transparent: physically demonstrate safe shut-down in worst case conditions vs. reliance on complex simulations and PRA calculations.