



HRVATSKA UDRUGA ZA
ZAŠTITU OD POŽARA
CROATIAN ASSOCIATION
FOR FIRE PROTECTION
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SIGURNOST NUKLEARNIH ELEKTRANA s posebnim osvrtom na sigurnost u slučaju požara

Prof.dr.sc. **Davor Grgić**, dipl.ing.el.

SVEUČILIŠTE U ZAGREBU
FAKULTET ZA ELEKTROTEHNIKU I RAČUNARSTVO
Zavod za visoki napon i energetiku

SEMINAR HRVATSKE UDRUGE ZA ZAŠTITU OD POŽARA

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Uvod 1

- Nuklearna elektrana je termoelektrana ali nema klasično gorivo koje može gorjeti
- Neke vrste elektrana imaju grafitni moderator (Černobil, Windscale) i to je specifični problem za taj tip reaktora ali ne za lakovodne reaktore
- Elektrana može biti oštećena požarom kao i bilo koji drugi energetska objekt: veliki transformatori (transformatorsko ulje), ulje za hlađenje ležajeva turbine i generatora, ulje za podmazivanje motora i pumpi (specifičnost primarne pumpe), vodik za hlađenje rotora generatora

Uvod 2

- Najveći problem je što požar može imati utjecaja na nuklearnu sigurnost objekta
- Afektirani mogu biti energetska, kontrolna i signalna kabela, motori, motorno upravljani ventili, rasklopni ormari, ugljeni filtri
- Ako ta oprema pripada sigurnosnim sustavima elektrane onda je moguć gubitak odgovarajuće sigurnosne funkcije i nesreća reaktora
- U nekim reaktorskim nesrećama nastaje H₂ koji može gorjeti ili eksplodirati i narušiti integritet zaštitne zgrade reaktora – nije predmet klasične borbe protiv požara

Uvod 3

- Požar može biti unutrašnji ili vanjski
- Većina vanjskih požara je eliminirana izborom lokacije i jedini relevantni problem je pad velikog aviona i posljedični požar goriva
- Osim uobičajenog zahtjeva za požarnu sigurnost objekta u NE se požar tretira i sa stajališta utjecaja na nuklearnu sigurnost (jedan je od common cause faktora i požarne zone objekta su povezane s fizičkom i prostornom separacijom)

Key aspects of fire protection in nuclear power plants US NRC

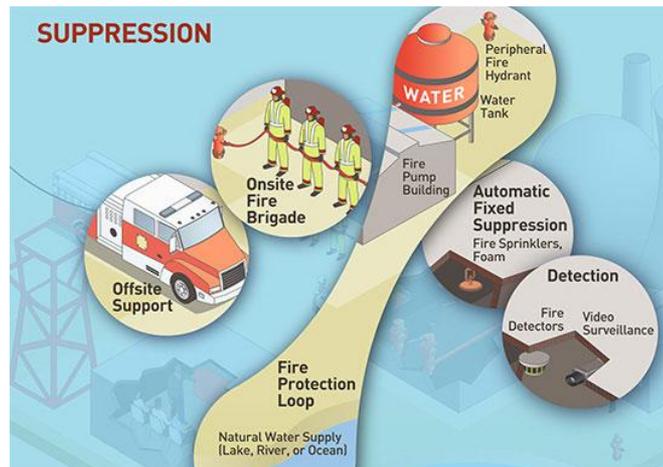
- **Layered defense-in-depth:** Plants use a "defense-in-depth" approach, meaning multiple, independent layers of protection are in place to compensate for potential failures.
- **Prevention:** Efforts are made to minimize fire risk by carefully designing and constructing the plant, limiting combustible materials, and using features like fire barriers (e.g., fire-resistant insulation, fire-proof doors, and dampers) to compartmentalize spaces and prevent fire propagation.
- **Detection and suppression:** Systems are installed to rapidly detect fires and automatically or manually extinguish them, which limits damage and helps maintain the safety of critical components.

Key aspects of fire protection in nuclear power plants

- **Safe shutdown capability:** A primary goal is to ensure that a fire does not prevent the reactor from being brought to a safe shutdown state. This requires redundant systems to be protected from fire damage, as outlined in the plant's **fire protection program**.
- **Emergency response:** Plants have detailed emergency response plans that are activated immediately in the event of a fire. These plans include procedures for:
 - Notifying local authorities and emergency responders
 - Monitoring for any release of radioactive materials
 - Evacuating personnel if necessary

Key aspects of fire protection in nuclear power plants

- **Training and drills:** Plant personnel and local fire departments are trained in fire safety procedures and coordinated drills are conducted to ensure a quick and effective response.
- **Regulatory oversight** : Nuclear power plants must submit and adhere to a comprehensive fire protection plan, and regulatory bodies conduct regular inspections to ensure compliance with regulations like 10 CFR Part 50.48 and Appendix R to Part 50.



Two approaches for managing NPP fire safety – US NRC

- **Deterministic fire protection** ensures reactor shutdown systems will survive an assumed serious fire. The NRC developed this approach when the best fire risk tools available to staff and the industry looked at an entire system. The NRC lists deterministic requirements in 10 CFR 50.48(b) and Appendix R of 10 CFR Part 50. [Regulatory Guide 1.189](#) provides plants an acceptable approach to meeting these requirements.
- **Risk-informed, performance-based fire protection** considers risk insights down to the individual component level, as well as other factors, to better focus attention and resources on design and operational issues according to their safety importance. This approach relies on a required outcome rather than requiring a specific process or technique to achieve that outcome. The NRC lists these requirements in 10 CFR 50.48(c).

Safety functions/ Fire damage limits

- **Hot shutdown**

- One train of equipment necessary to achieve hot shutdown from either the control room or emergency control station(s) must be maintained free of fire damage by a single fire, including an exposure fire.

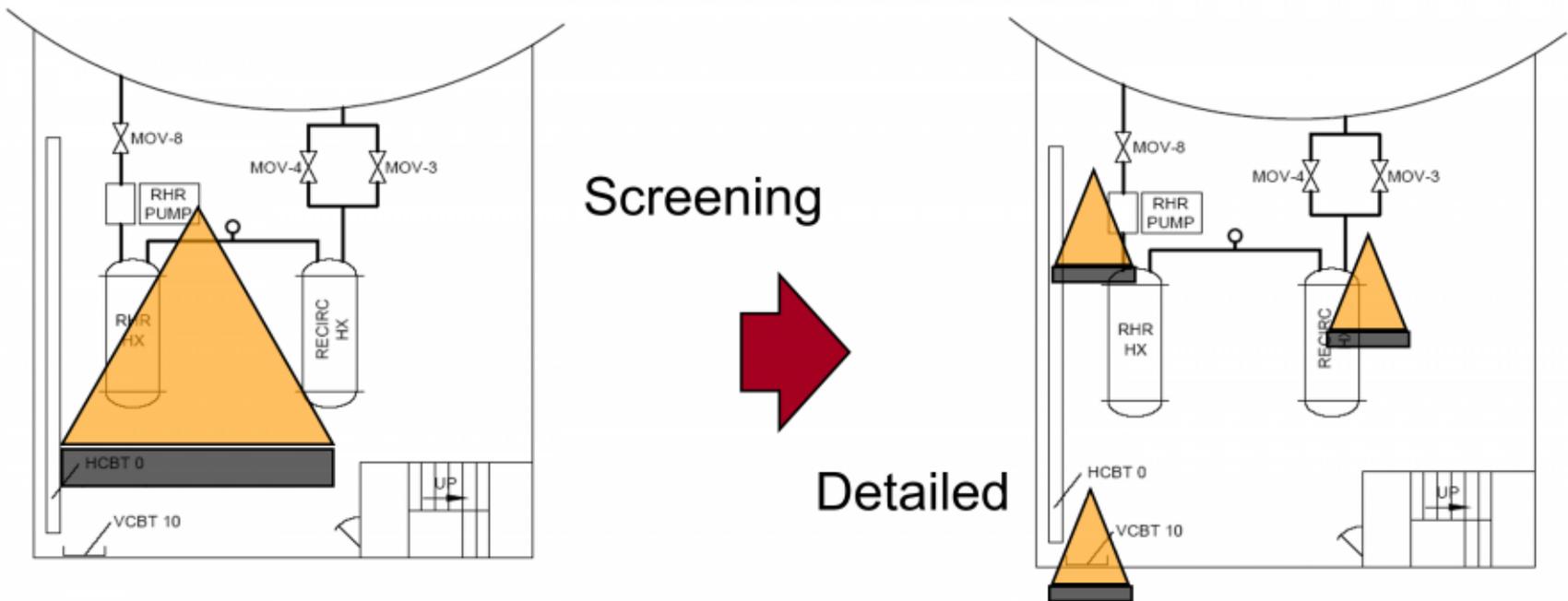
- **Cold shutdown**

- Both trains of equipment necessary to achieve cold shutdown may be damaged by a single fire, including an exposure fire, but damage must be limited so that at least one train can be repaired or made operable within 72 hours using onsite capability.

- **Design Basis Accidents**

- Both trains of equipment necessary for mitigation of consequences following design basis accidents may be damaged by a single exposure fire.

Fire scenarios, from screening to detailed fire modeling



Tools for PSA/PRA and FHA (Fire Hazard Analysis) and performance based fire

Fire Protection in Nuclear Power Plants

- **3.2 PASSIVE FIRE PROTECTION SYSTEM**
- 3.2.1 Spacing and layout
- 3.2.2 Structural barriers
- 3.2.3 Electrical cable system
- 3.2.4 Heating, ventilation, and air conditioning design
- 3.2.5 Containment and drainage
- 3.2.6 Emergency lighting
- 3.2.7 Communications
- **3.3 ACTIVE FIRE PROTECTION SYSTEMS**
- 3.3.1 Automatic versus manual activation
- 3.3.2 Detection and alarm system
- 3.3.3 Water supply system
- 3.3.4 Fire suppression system
- 3.3.5 Manual suppression systems and equipment
- **3.4 INSPECTION, TESTING, AND MAINTENANCE**

Fire Prevention Activities

- **4.1 CONTROL OF COMBUSTIBLE MATERIALS**
- 4.1.1 Combustible materials hazard identification
- 4.1.2 Types of combustibles
- 4.1.3 Control of combustibles
- **4.2 CONTROL OF IGNITION SOURCES**
- 4.2.1 Hot work
- 4.2.2 Personal ignition sources
- 4.2.3 Static electricity
- 4.2.4 Electrical area classification
- **4.3 HOUSEKEEPING**
- 4.3.1 Housekeeping program
- 4.3.2 Process area housekeeping
- 4.3.3 Dust control
- 4.3.4 Inappropriate storage and handling
- 4.3.5 Housekeeping and equipment
- 4.3.6 Cleaning materials

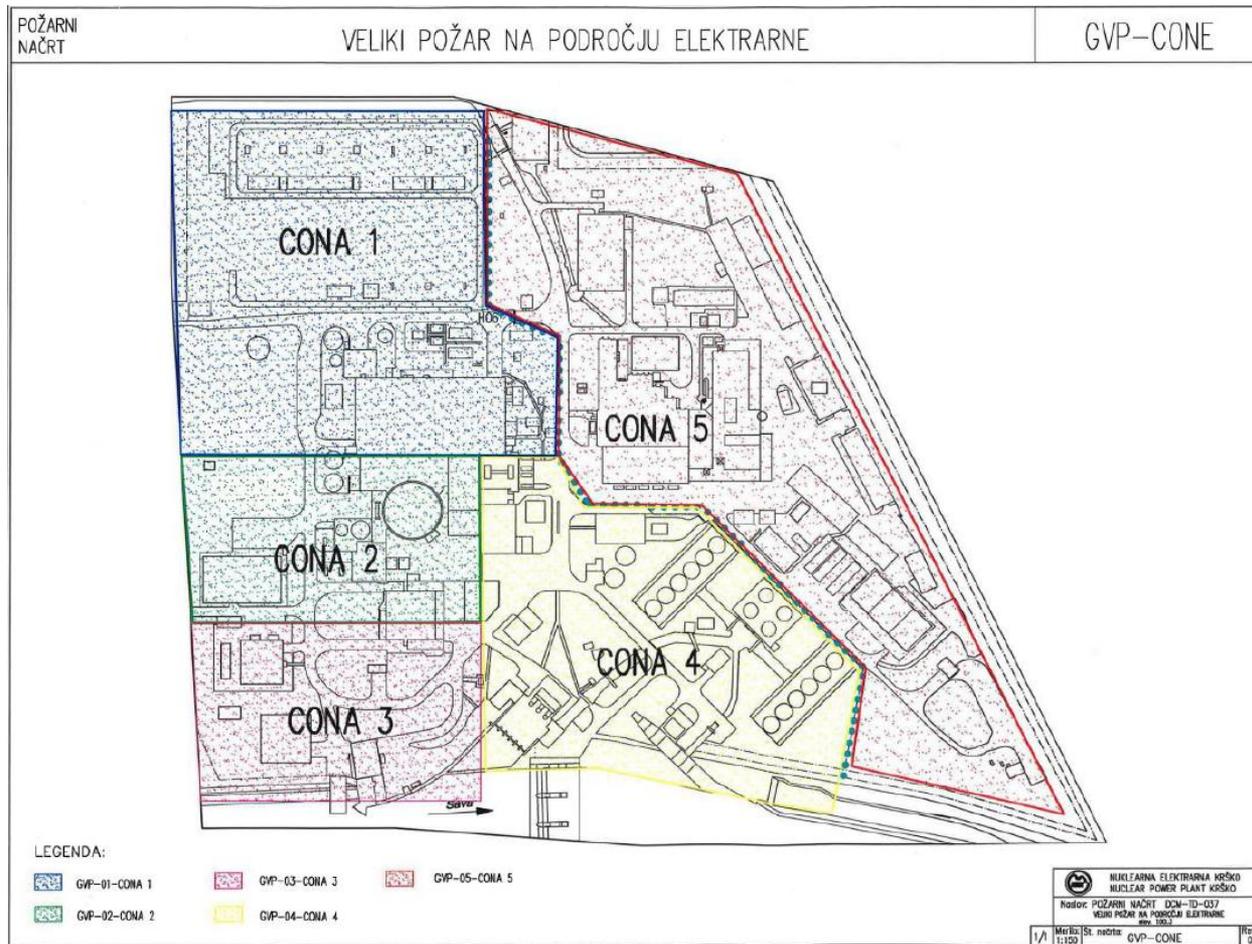
Fire Risk Analysis

- **5.1 FIRE RISK ANALYSIS OVERVIEW**
- 5.1.1 Objectives of fire risk analysis
- 5.1.2 Fire risk analysis concept
- 5.1.3 Fire risk analysis documentation
- **5.2 IDENTIFYING AND ANALYZING FIRE HAZARDS IN THE PLANT**
- 5.2.1 Design basis fire
- 5.2.2 Calculate potential hazard
- **5.3 SAFE SHUTDOWN ANALYSIS**
- 5.3.1 Effect on SSCs important to safety
- 5.3.2 Deterministic approach and probabilistic approach
- **5.4 PROBABILISTIC SAFETY ANALYSIS**
- **5.5 VULNERABILITY DETERMINATION**
- 5.5.1 Introduction
- 5.5.2 Post-fire safe shutdown analysis
- 5.5.3 Application of fire hazard analysis
- 5.5.4 Impacts of plant modifications
- **5.6 SPECIAL CONSIDERATIONS**
- 5.6.1 Seismic induced fires
- 5.6.2 Beyond design basis fires

Razmještaj objekata na lokaciji NE

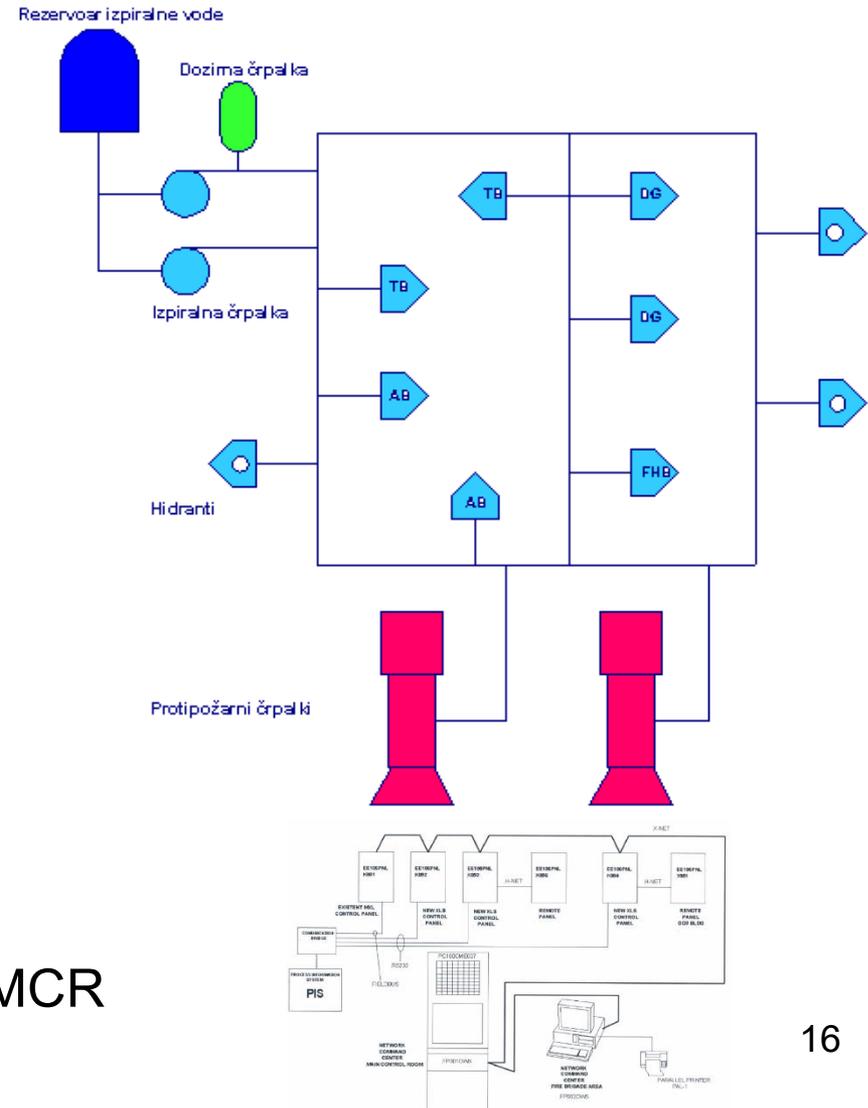


Veliki vanjski požar (pad aviona)



Protupožarni sistem, fiksna i mobilna oprema

- Automatsko gašenje
- Prstenasta konfiguracija
- Omogućeno višestrano napajanje
- Sustav napunjen vodom i u stanju pripravnosti 8.1-8.8 bar
- Dimni i toplinski detektori ili ručni start
- Na pad tlaka auto start:
 - Flashing na 6 bar (150 m³/h)
 - Električna na 5.3 bar (570 m³/h)
 - Dizel na 4.6 bar (usis Sava)
- Ručni uređaji za gašenje
- Požarne centrale u postrojenju i MCR

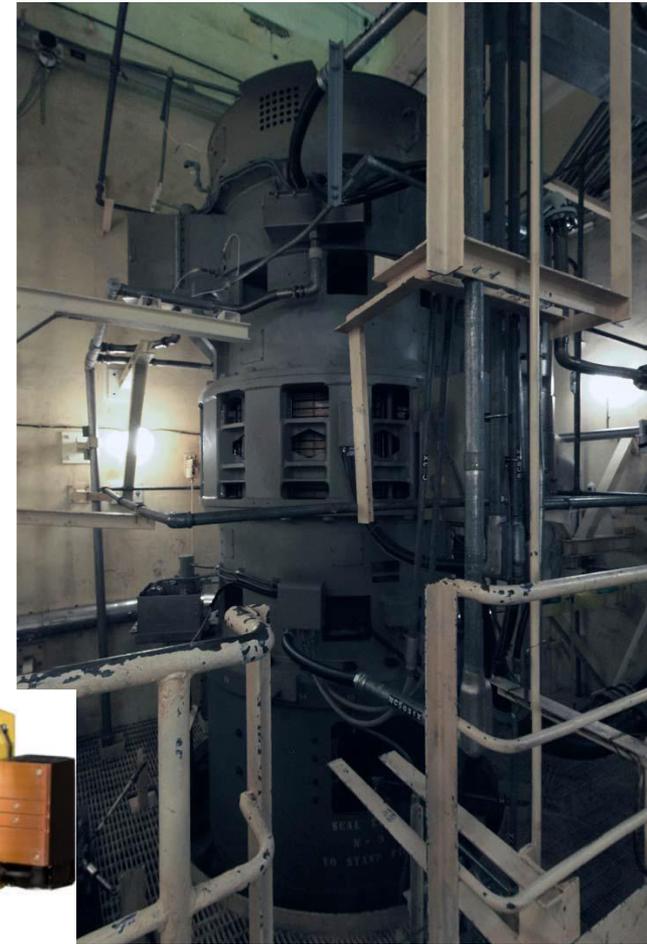
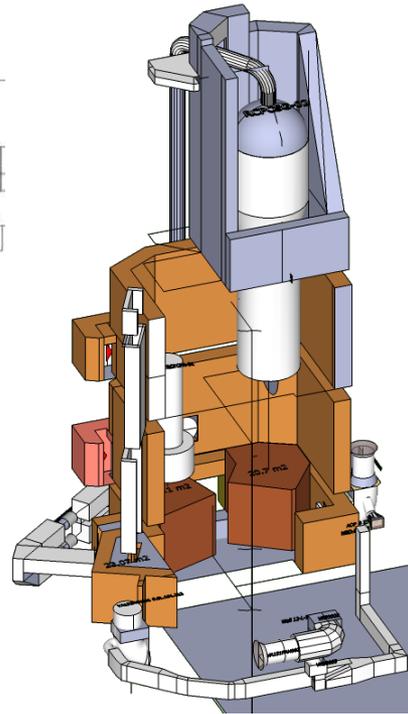
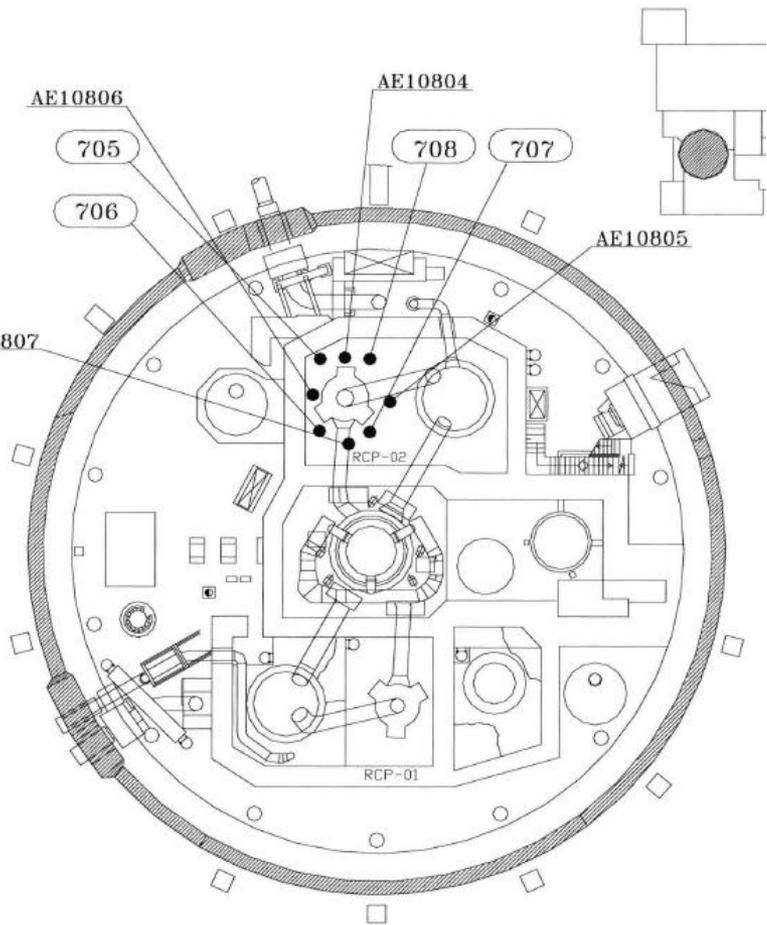


Ljudstvo vlastito + vanjsko

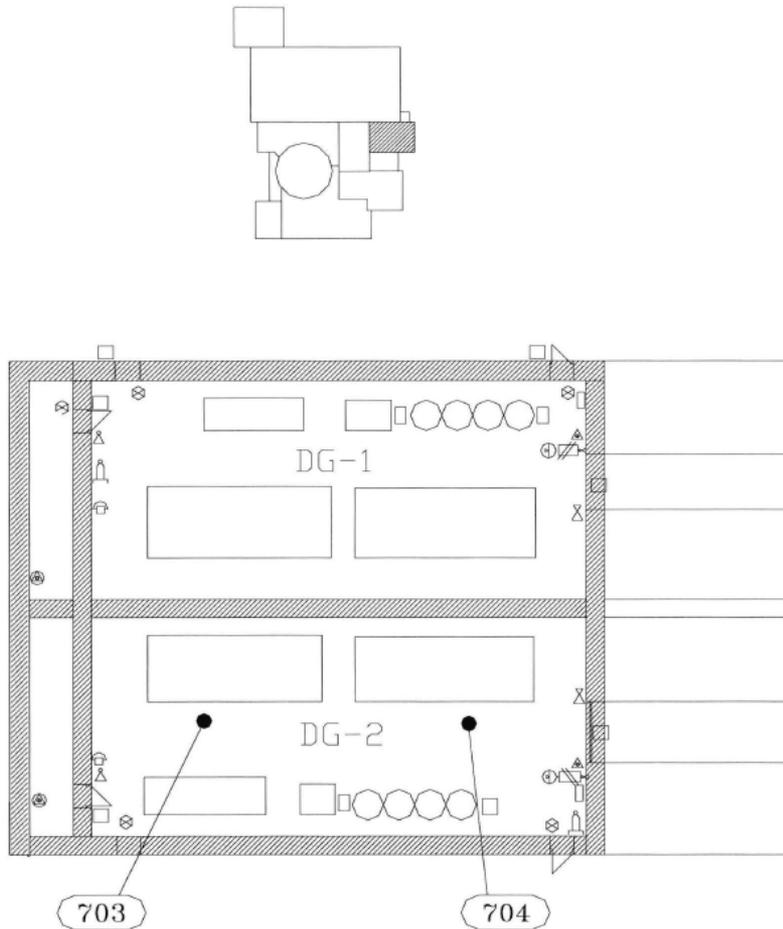
- 3 vatrogasca u smjeni (1 NEK + 2 DVD)
- 4 sekundarno raspoloživa lokalna operatera
- DVD/PGE
 - 3 unutar 10 minuta
 - dodatnih 10 unutar 30 minuta
 - dodatnih 20 unutar 60 minuta od poziva
- Vatrogasni vod (23 osobe)
- Gašenje požara i spašavanje
- Stalna obuka na nivou NEK osnovna i specijalistička
- Raspoloživost širokog spektara mobilne opreme



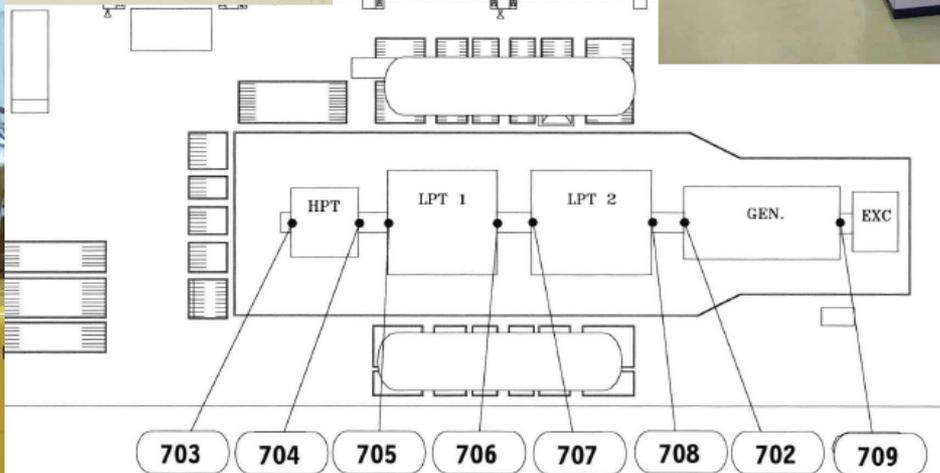
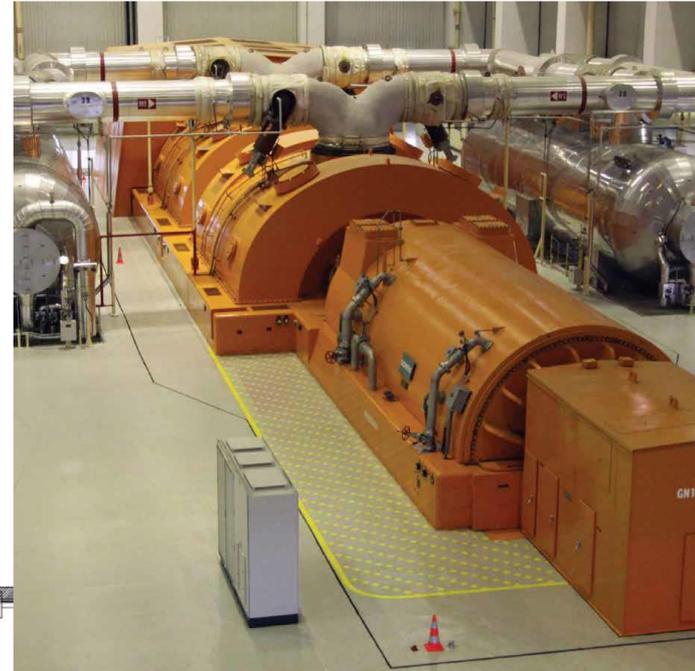
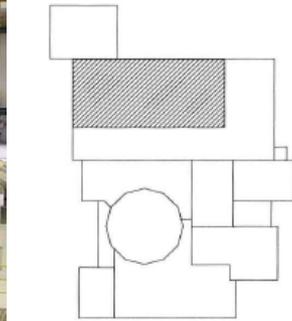
RCP motor, toplinski i dimni detektor, video kamera, sprinkler sustav



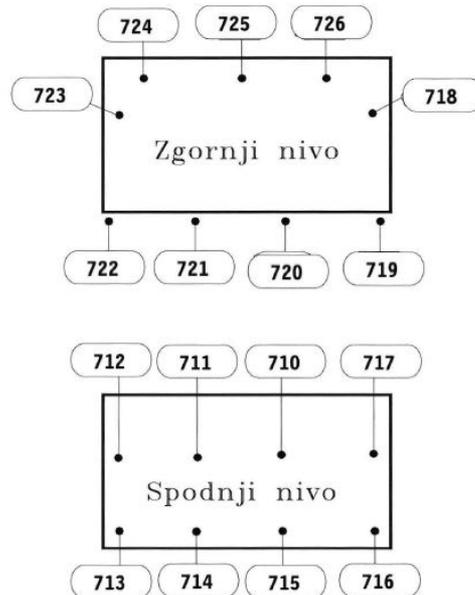
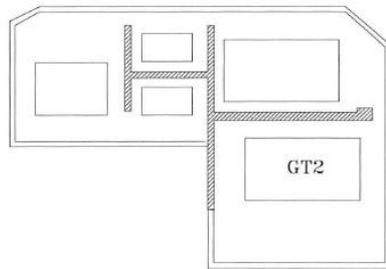
EDG, dnevni i tjedni spremnik goriva



Toplinski detektori turbinskih ležajeva s aktivacijom sprej mlaznica



Toplinski detektori GT2 i stabilni sustav za gašenje vodom



Aktivacijski ventili automatskog spreja transformatora



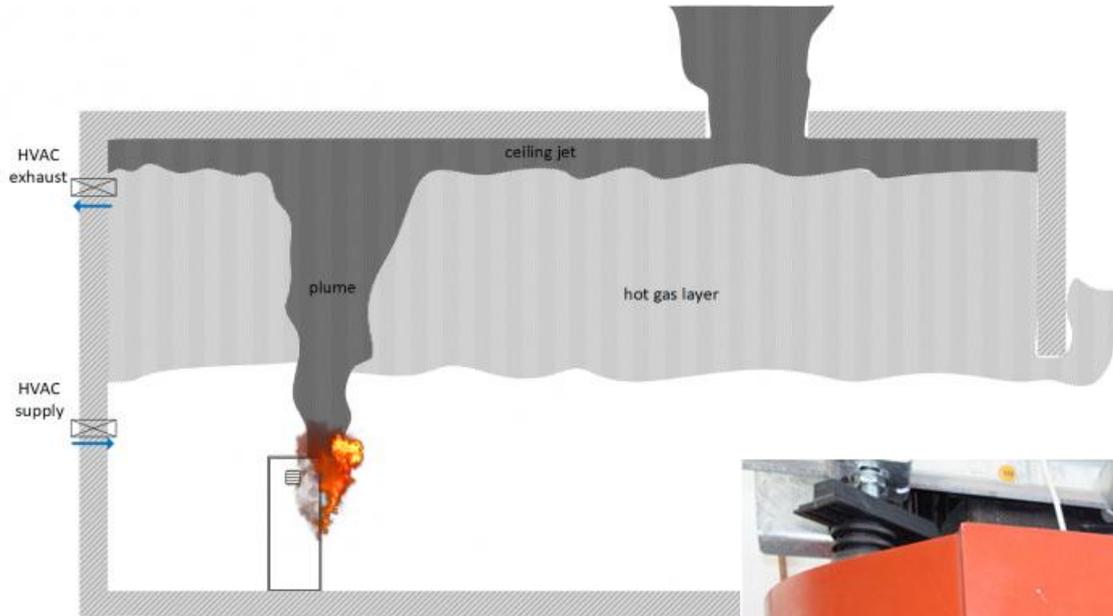
Vanjski dio sustava za gašenje ugljenih filtera ventilacije VA72111 (RB), pruga A i B



Tipičan izgled sobe sa sigurnosnom opremom



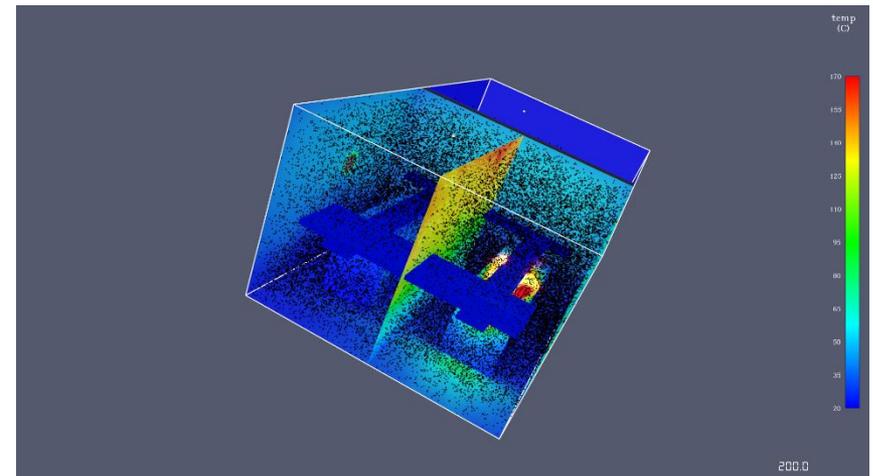
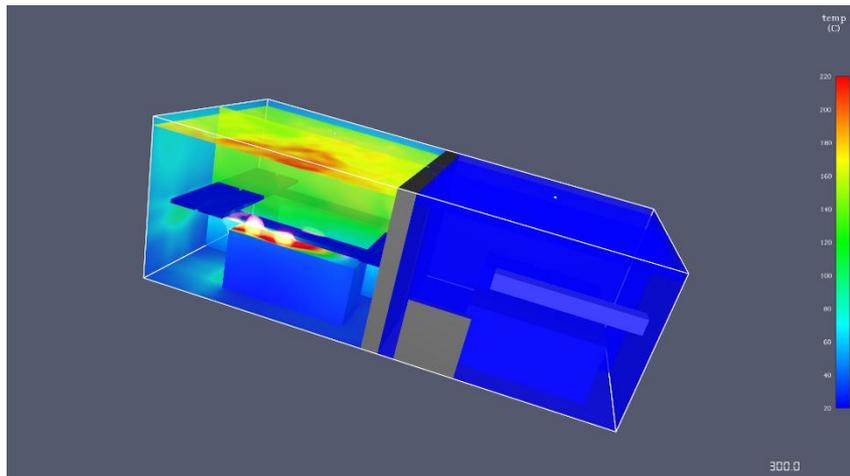
Performance based fire modeling and operational events



- NEK 30.07.2025 04:41
- Proboj suhog 6.3 kV transformatora T41
- Dim bez porasta topline
- Bez aktivacije FP alarma
- Stratifikacija dima
- Nadstrujna i podnaponska zaštita

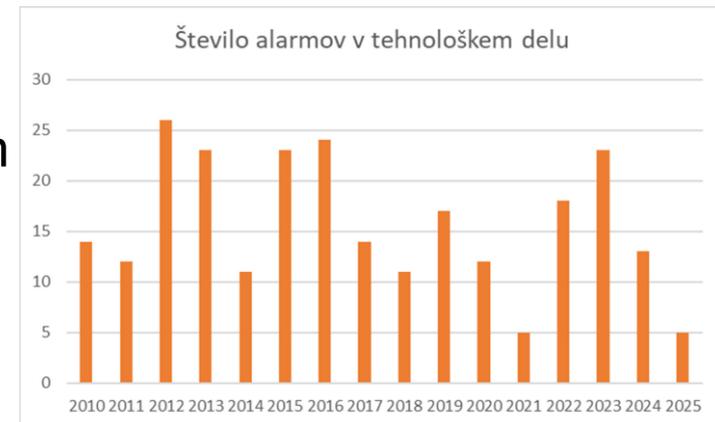


Ormari s električnom opremom i kableske police (FDS)



Požarna sigurnost - indikatori

- Požarni događaji
- Oprema i sustavi
 - Stabilni sustavi za gašenje
 - FP pumpe
 - Vanjski i unutrašnji hidrantski sustav
 - Požarni aparati
 - Požarne barijere, kontrola gorivog materijala i dijela s toplinskim učinkom
 - Sustav za detekciju požara
 - Oprema vatrogasci NEK/PGE
- Osoblje
- Program požarne zaštite
- Testiranje i održavanje protupožarnih sustava



Da li su NE sigurne?

- Mogući odgovori:
 - Ne, to su tempirane atomske bombe
 - Da, produkt su suvremene tehnologije i svaka moguća nesreća je uzeta u obzir
 - Da, ali obzirom na prirodu procesa stanoviti rizik je prisutan
- U čemu je opasnost?
- Što je s drugim energetske izvori, da li se rizik isplati?
- Zašto zadnje vrijeme češće govorimo o nuklearnim elektranama?

Definitions



Nuclear safety:

“The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards.”

Nuclear security:

“The prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities.”

Nuclear safeguards:

“A set of technical measures applied by the IAEA on nuclear material and activities, through which the Agency seeks to independently verify that nuclear facilities are not misused and nuclear material not diverted from peaceful uses.”

Pod kojim uvjetima je rad nuklearnih elektrana prihvatljiv?

- NE moraju biti sigurne i pouzdane (nove generacije elektrana unapređuju ionako pouzdanu tehnologiju, ali se javlja problem terorizma) da bi utjecaj na okoliš bio minimalan
- NE moraju biti konkurentne (porast cijene fosilnih goriva, njihova moguća nestašica, utjecaj na okoliš i eksterni troškovi, predvidljivost i promjenjivost OIE, zauzeće prostora i potrošnja materijala)
- Potrebno je riješiti problem istrošenog goriva (problem je tehnički rješiv i radi se na par demonstracijskih projekata, transmutacija bi mogla bitno popraviti situaciju)
- Spriječiti proliferaciju nuklearnog materijala (uglavnom političko pitanje i nije nužno vezano za energetska primjenu)

Da li nuklearne elektrane imaju budućnost?

Da, ako nastave biti sigurne i pouzdane uz prihvatljivu proizvodnu cijenu električne energije i ako demonstriraju dugoročnu stabilnost za ulaganje i neovisnost od cijena goriva.

Za razliku od fosilnih tehnologija zahtjevi za zaštitu okoliša, razgradnju i slično već su uzeti u obzir.

Za razliku od OIE NE su on demand izvori

Sigurnost i pouzdanost

Prihvatljiva cijena

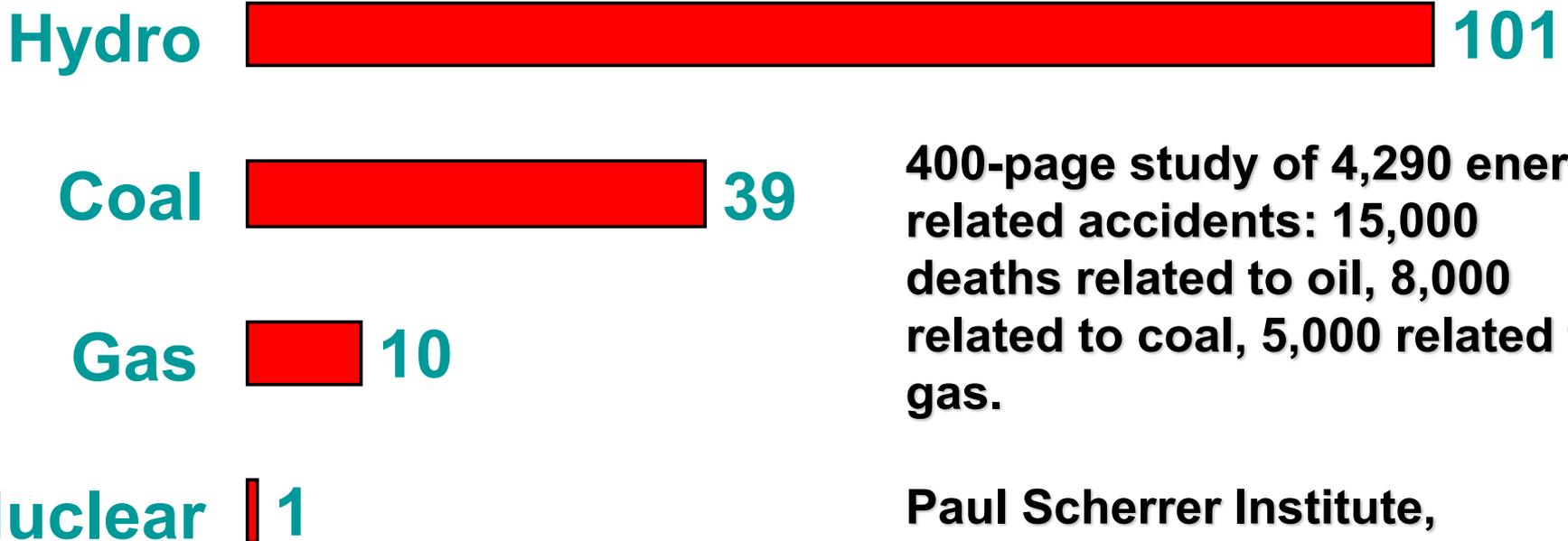
Dugoročna stabilnost i sigurnost opskrbe

Prihvatljiv utjecaj na okoliš



Nuklearni i klasični energetska izvori

Deaths from Accidents from Generating Electricity per Billion MWe-hr



400-page study of 4,290 energy-related accidents: 15,000 deaths related to oil, 8,000 related to coal, 5,000 related to gas.

Paul Scherrer Institute, Switzerland, 2001

*Includes Chernobyl

Some energy-related accidents since 1977

Place	year	number killed	comments
Machhu II, India	1979	2500	hydro-electric dam failure
Hirakud, India	1980	1000	hydro-electric dam failure
Ortuella, Spain	1980	70	gas explosion
Donbass, Ukraine	1980	68	coal mine methane explosion
Israel	1982	89	gas explosion
Guavio, Colombia	1983	160	hydro-electric dam failure
Nile R, Egypt	1983	317	LPG explosion
Cubatao, Brazil	1984	508	oil fire
Mexico City	1984	498	LPG explosion
Tbilisi, Russia	1984	100	gas explosion
northern Taiwan	1984	314	3 coal mine accidents

Some energy-related accidents since 1977

Chernobyl, Ukraine	1986	31+	nuclear reactor accident
Piper Alpha, North Sea	1988	167	explosion of offshore oil platform
Asha-ufa, Siberia	1989	600	LPG pipeline leak and fire
Dobrnja, Yugoslavia	1990	178	coal mine
Hongton, Shanxi, China	1991	147	coal mine
Belci, Romania	1991	116	hydro-electric dam failure
Kozlu, Turkey	1992	272	coal mine methane explosion
Cuenca, Ecuador	1993	200	coal mine
Durunkha, Egypt	1994	580	fuel depot hit by lightning
Seoul, S.Korea	1994	500	oil fire
Minanao, Philippines	1994	90	coal mine
Dhanbad, India	1995	70	coal mine

Some energy-related accidents since 1977

Taegu, S.Korea	1995	100	oil & gas explosion
Spitsbergen, Russia	1996	141	coal mine
Henan, China	1996	84	coal mine methane explosion
Datong, China	1996	114	coal mine methane explosion
Henan, China	1997	89	coal mine methane explosion
Fushun, China	1997	68	coal mine methane explosion
Kuzbass, Siberia	1997	67	coal mine methane explosion
Huainan, China	1997	89	coal mine methane explosion
Huainan, China	1997	45	coal mine methane explosion
Guizhou, China	1997	43	coal mine methane explosion
Donbass, Ukraine	1998	63	coal mine methane explosion
Liaoning, China	1998	71	coal mine methane explosion

Some energy-related accidents since 1977

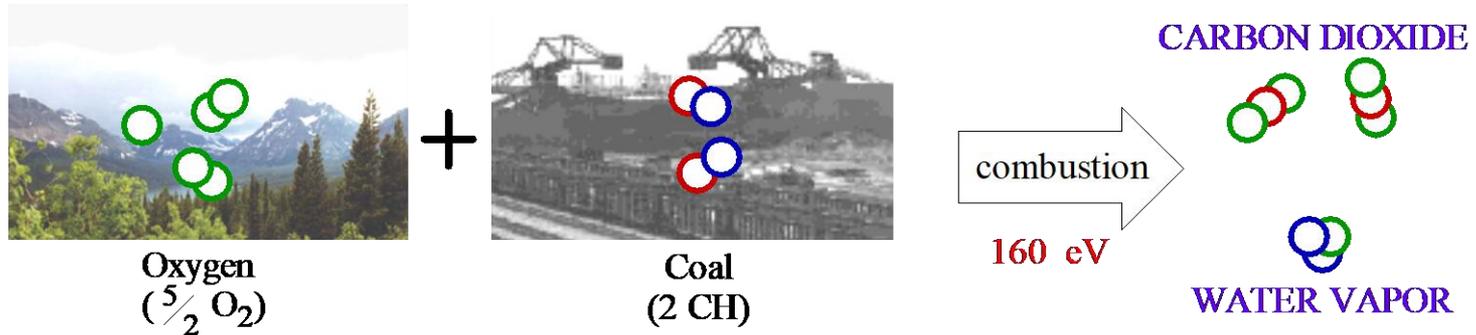
Warri, Nigeria	1998	500+	oil pipeline leak and fire
Donbass, Ukraine	1999	50+	coal mine methane explosion
Donbass, Ukraine	2000	80	coal mine methane explosion
Shanxi, China	2000	40	coal mine methane explosion
Guizhou, China	2000	150	coal mine methane explosion
Shanxi, China	2001	38	coal mine methane explosion
Sichuan, China	2002	23	coal mine methane explosion
Jixi, China	2002	115	coal mine methane explosion

Comparison of accident statistics in primary energy production

Fuel	Immediate fatalities 1970-92	Who?	Deaths per TWy* electricity
Coal	6400	workers	342
Natural gas	1200	workers & public	85
Hydro	4000	public	883
Nuclear	31	workers	8

Electricity generation accounts for about 40% of total primary energy

Energija iz fosilnih goriva



- Fossil Fuel (Coal) Energy Density: 2.9×10^7 J/kg
- Fuel Consumed by 1000-MW_e Plant: 7,300,000 kg/day
- Waste:

Coal Combustion Products

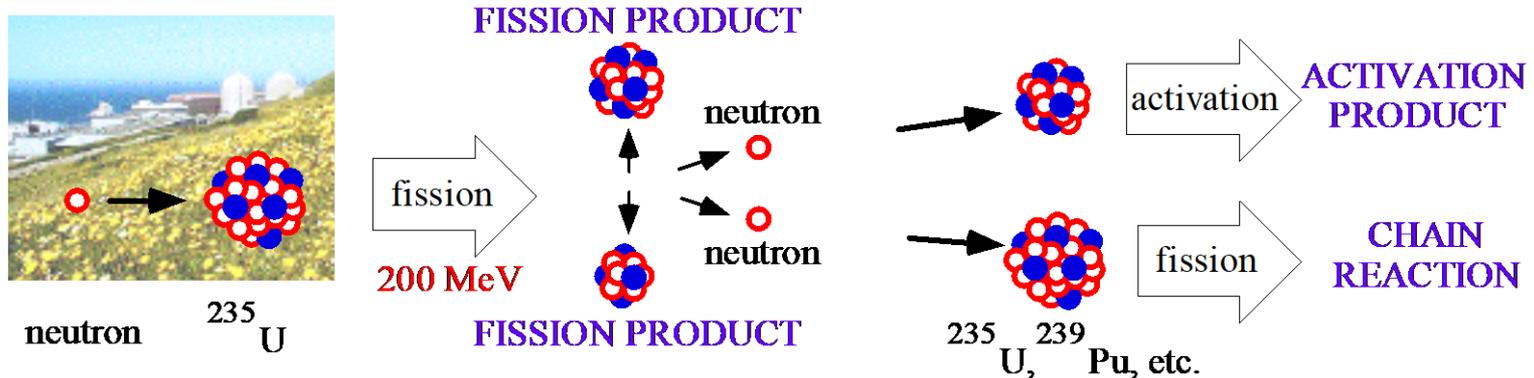
- NO_x → High temperature combustion
- SO_x → Sulfur in coal (0.4% - 5%)
- Ash → (5% - 25% of coal mass)
- CO₂ → Global warming

Mining

- Leachates/
dust from
mining
- Construction
materials

1999 Global Coal Consumption: 3 billion tons

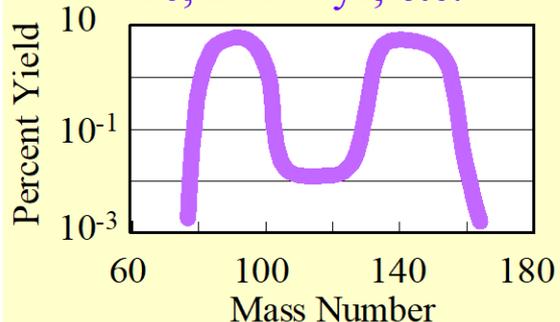
Energija nuklearne fisije



- **Fission Fuel Energy Density:** 8.2×10^{13} J/kg (20,000 t_{HE} /kg)
- **Fuel Consumed by 1000-MW_e Plant:** 3.2 kg/day
- **Waste:**

Fission Prod. (3.2 kg/day)

^{90}Sr , 30 yr; ^{137}Cs , 30 yr;
 ^{99}Tc , 2×10^5 yr; etc.



Activation Products

Fuel → Transuranics, longer half lives (^{239}Pu , 24,000 yr; ^{237}Np , 2×10^6 yr; etc.)

Structures → Moderate half lives, low-level waste (^{60}Co , 5 yr)

Coolants → Low (water) to moderate (metals) half lives

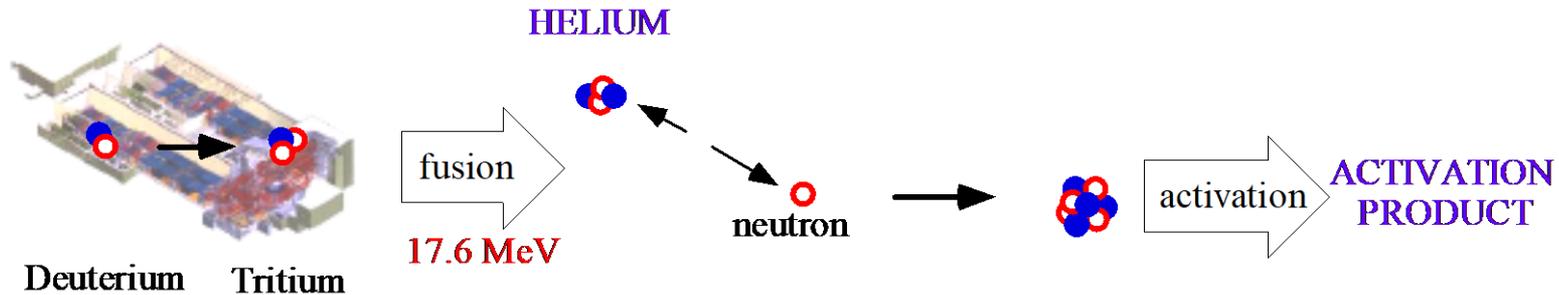
Transmutation → Convert from long to short half life

Mining

Radon from mill tails if not capped

Construction materials

Energija nuklearne fuzije



- Fusion Fuel Energy Density: 3.4×10^{14} J/kg
- Fuel Consumed by 1000-MW_e Plant: 0.6 kg/day
- Waste:

Activation Products

Structures → Moderate half lives, depends strongly on material selection (low atomic mass better)

Coolants → Short half lives (low atomic mass)

Blanket → $n + {}^6\text{Li} \rightarrow 4\text{He} + \text{T}$
 $n + {}^m\text{M} \rightarrow 2n + {}^{m-1}\text{M}$

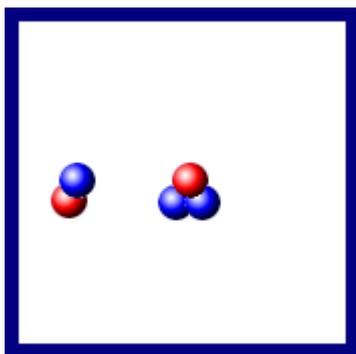
Mining

Construction materials

Energija iz atomske jezgre

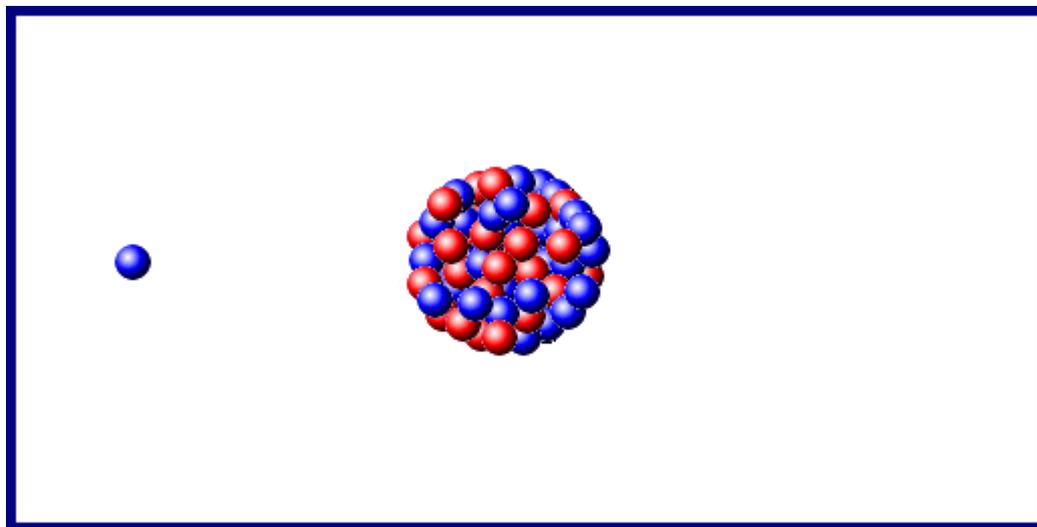
Fuzija

Spajanje manjih jezgri u veću

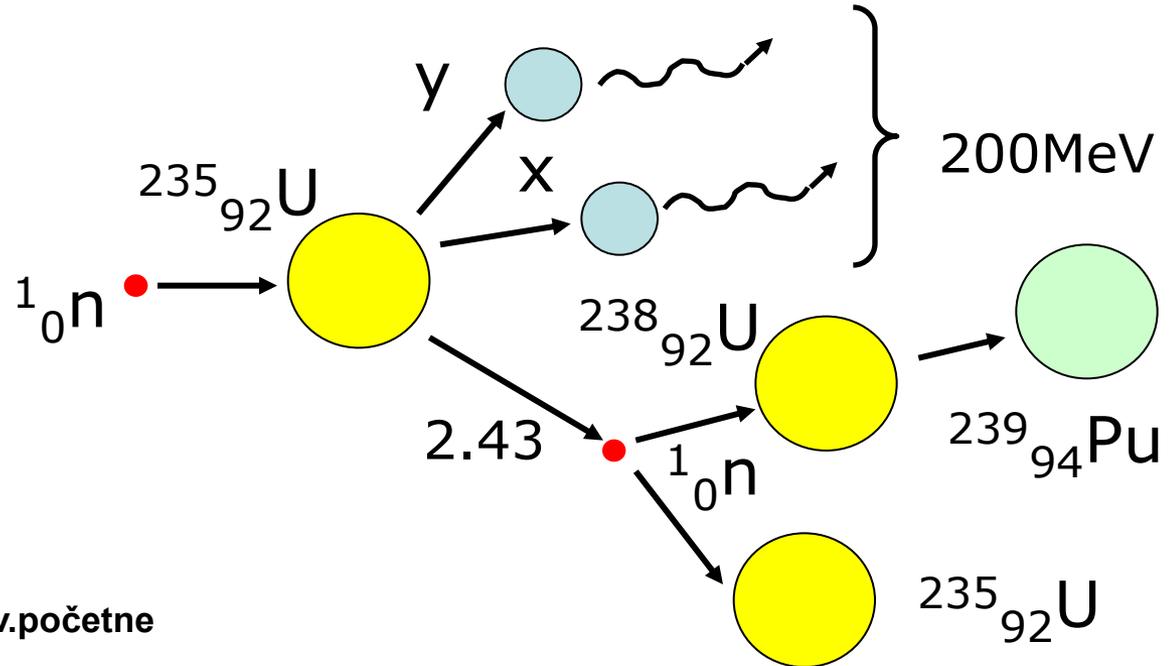


Fisija

Raspad teških jezgri na lakše



Fisija Urana



Fisija: $\Delta E_{\text{vezanja}} > E_{\text{aktivacije}}$

$$\Delta E_{\text{vezanja.jezgre}} = E_{\text{v.nastale}} - E_{\text{v.početne}}$$

$E_{\text{aktivacije}}$ = potrebna energija za fisiju

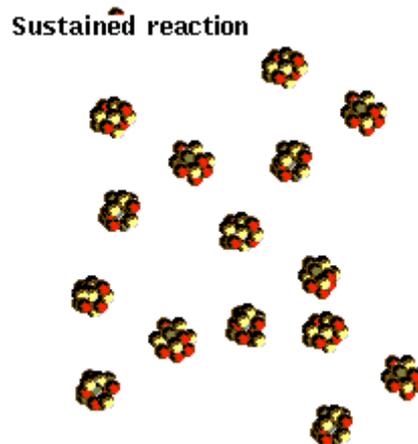
U235 – fisibilan

U238 – fisibilan s pragom

$$1 \text{ eV} = 1,60219\text{E-}19 \text{ J}$$

$$200 \text{ Mev} = 3,204\text{E-}11 \text{ J}$$

$$1 \text{ W} = 3,124\text{E}10 \text{ fisija}$$

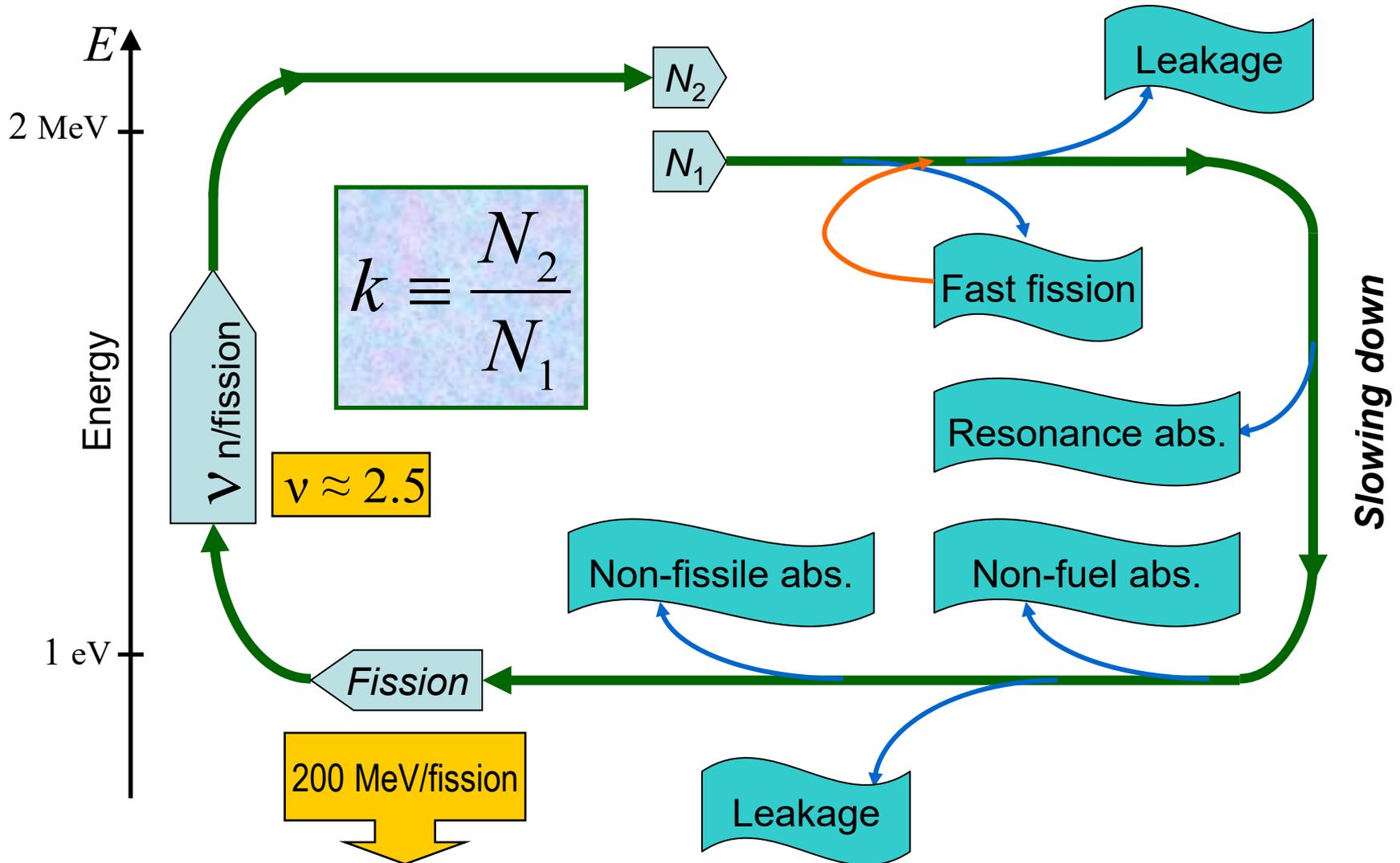


Energija iz fisije	
Kinetička fragmenata	83.5%
Trenutne γ -zrake	2.5%
Kinetička neutrona	2.5%
β -raspad fragmenata	3.5%
γ zrake fragmenata	3.0%
Energija neutrina	5.0%

Nuklearni reaktor

- Nuklearni reaktor je sustav projektiran da omogući kontroliranu samoodržavajuću nuklearnu reakciju fisije
- Parametar koji opisuje tijek odvijanja procesa naziva se multiplikacijski faktor k .
- Definiran je kao omjer srednjeg broja neutrona u dvije susjedne generacije neutrona (prije i poslije fisije)
- Da bi se nuklearna reakcija mogla nadzirati njegova vrijednost ne smije biti puno veća od 1
- Reaktor koji ima $k=1$ zovemo kritičnim reaktorom i on održava konstantan broj neutrona i snagu proizvedenu fisijom
- Ako je $k<1$ broj neutrona i snaga reaktora će se s vremenom smanjivati i reaktor zovemo podkritičnim a ako je $k>1$ broj neutrona u reaktoru i snaga reaktora će se povećavati i reaktor zovemo nadkritičnim
- Kako je k u praksi vrlo blizu 1 uvedena je veličina koja se naziva reaktivnost i definirana je kao $\rho=(k-1)/k$ i predstavlja relativno odstupanje reaktora od kritičnog stanja

Ciklus neutrona u reaktoru

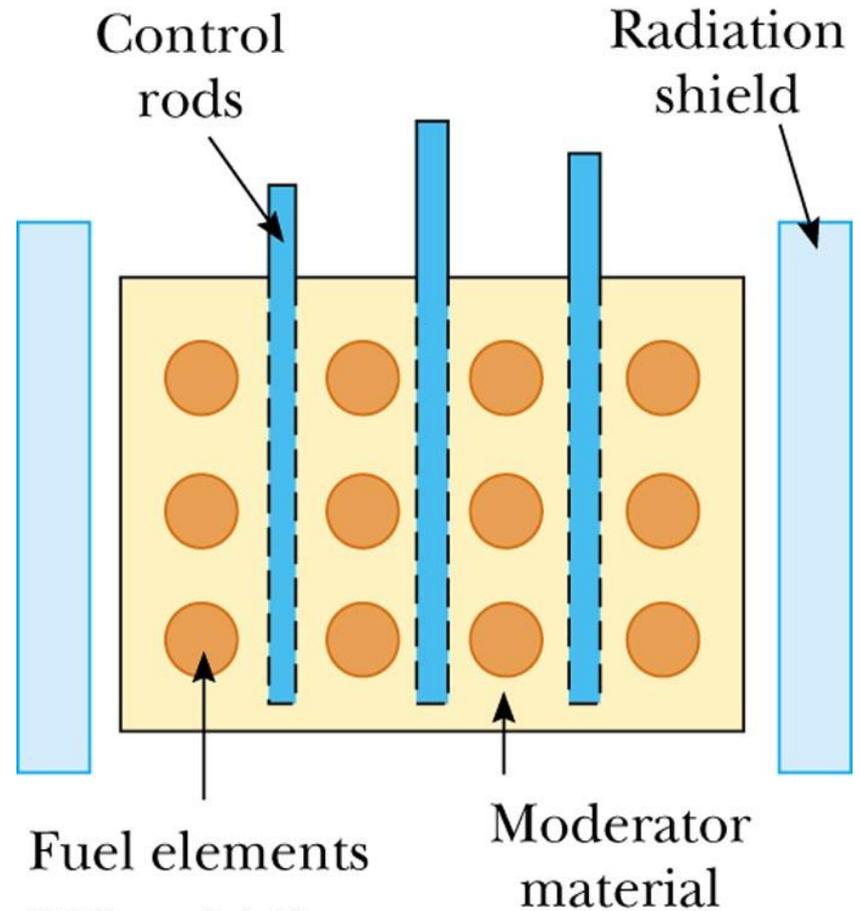


Ciklus neutrona u reaktoru

- Neutroni su unutar reaktora podvrgnuti procesu difuzije (struje od mjesta veće gustoće prema mjestu niže gustoće)
- Za kritičnost reaktora bitne su dvije vrste neutrona
- Promptni neutroni nastaju direktno pri fisiji
- Zakašnjeli neutroni su rezultata raspada fisijskih produkata
- Udjel zakašnjelih neutrona u ukupnom broju neutrona je od 0.22% do 0.65%
- Najveći broj zakašnjelih neutrona se pojavi unutar 70 s nakon procesa fisije
- Zakašnjeli neutroni su bitni za kontrolu reaktora

Osnovni izgled reaktora

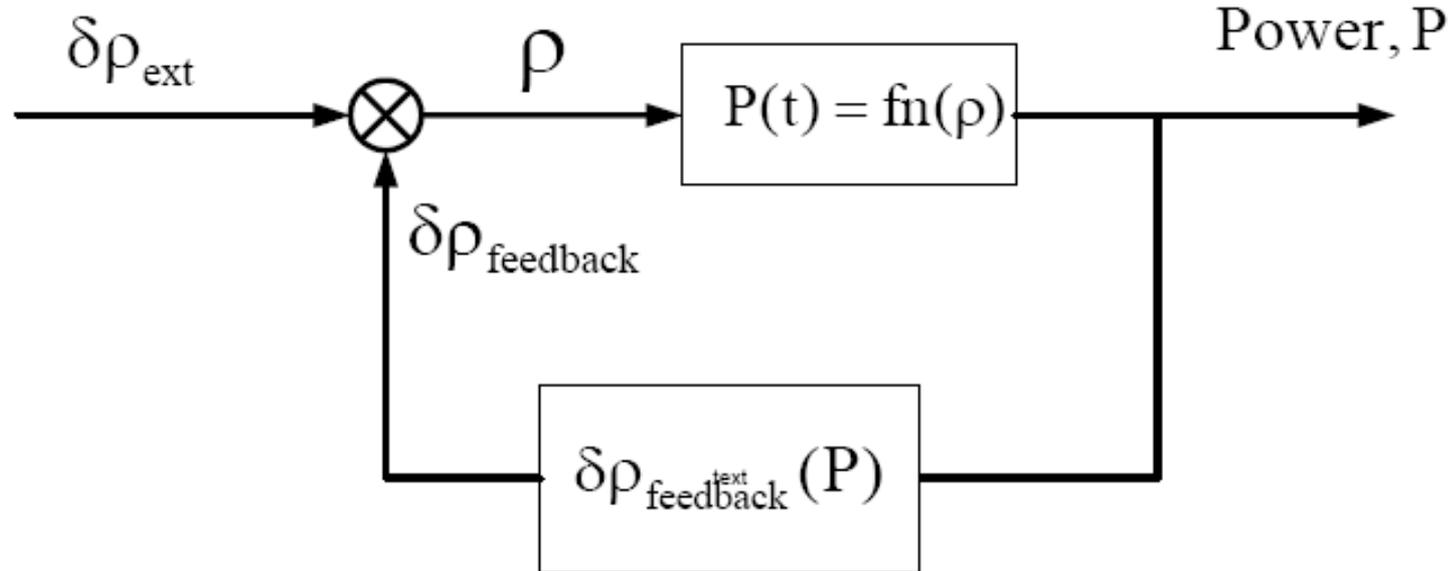
- Nuklearno gorivo je organizirano u gorivne elemente
- Moderator je materijal koji ima sposobnost usporavanja neutrona
- Rashladno sredstvo odvodi toplinu iz reaktora
- Posebni kontrolni elementi napravljeni od materijala koji absorbiraju neutrone služe za nadzor broja neutrona raspoloživih za fisiju
- Nuklearno gorivo, moderator, rashladno sredstvo i kontrolni element čine jezgru reaktora
- Jezgra je okružena štitom od zračenja



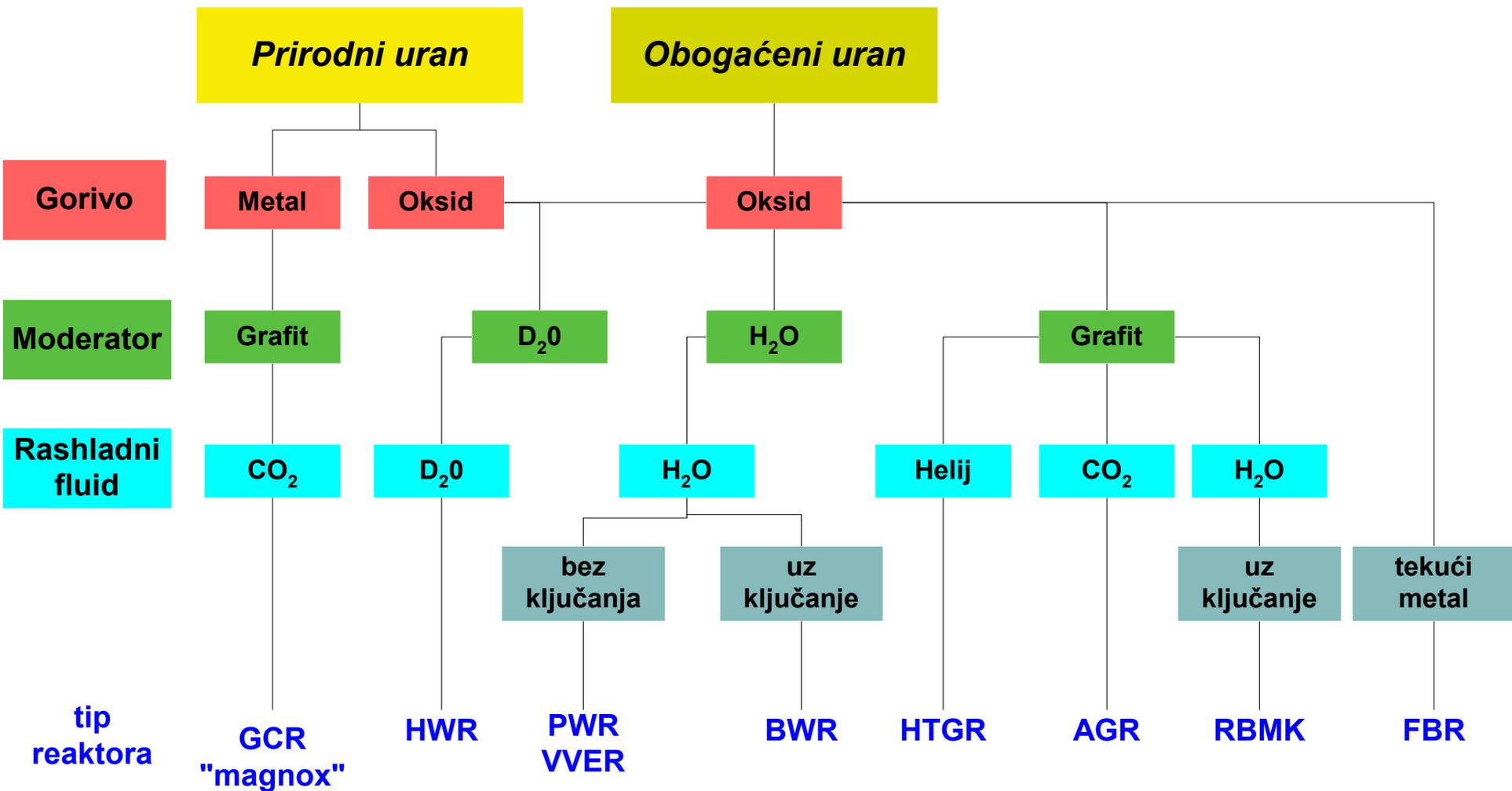
© 2003 Thomson - Brooks Cole

Thermal-hydraulics Feedback

Temperaturni koeficijenti reaktivnosti



Kriteriji za podjelu NE



Ostatna toplina

Generirana snaga
nakon obustave reaktora:

- ostatna toplina posljedica je radioaktivnog raspada fisijskih produkata

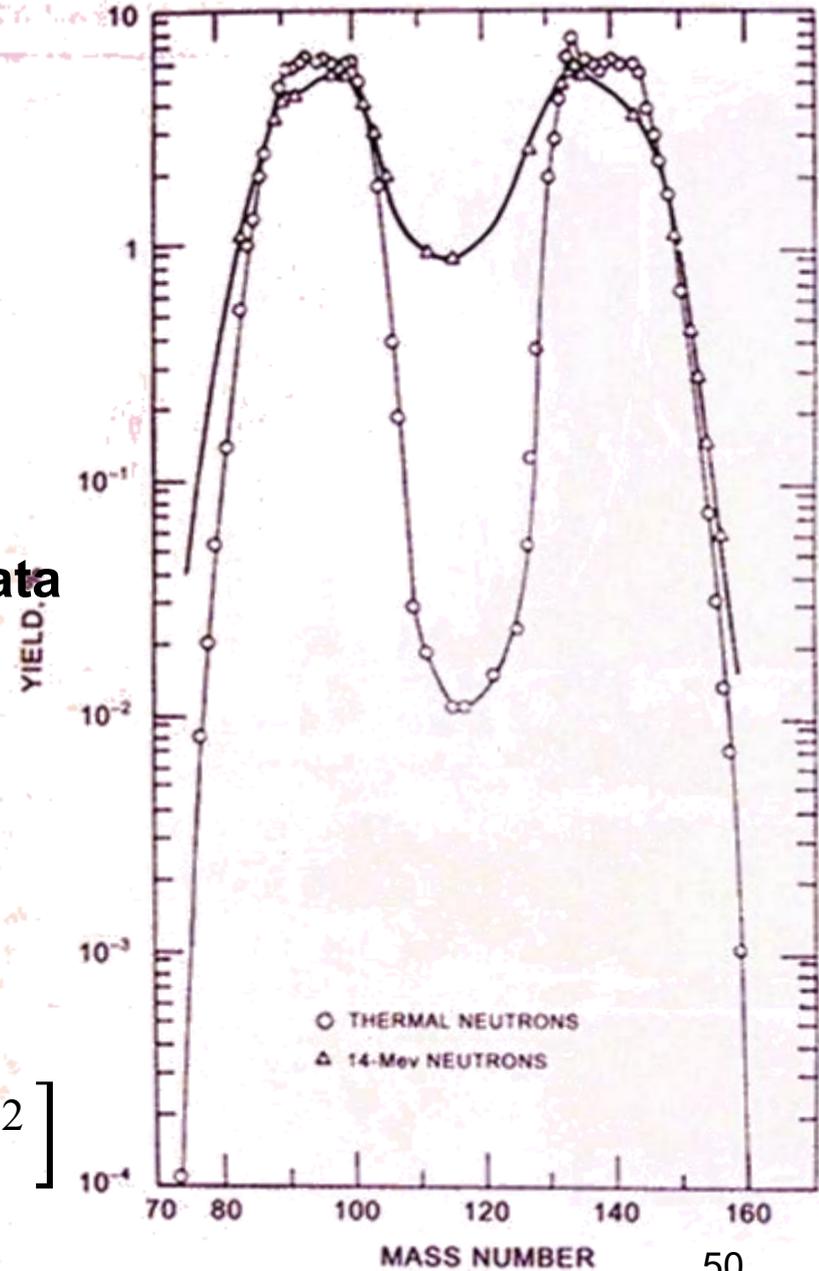
P_0 – snaga reaktora prije obustave

t_0 – vrijeme rada reaktora

t – vrijeme rada i obustave

(vremena su u danima)

$$P = P_0 \cdot 0,0061 \cdot \left[(t - t_0)^{-0,2} - t^{-0,2} \right]$$



Ostatna toplina

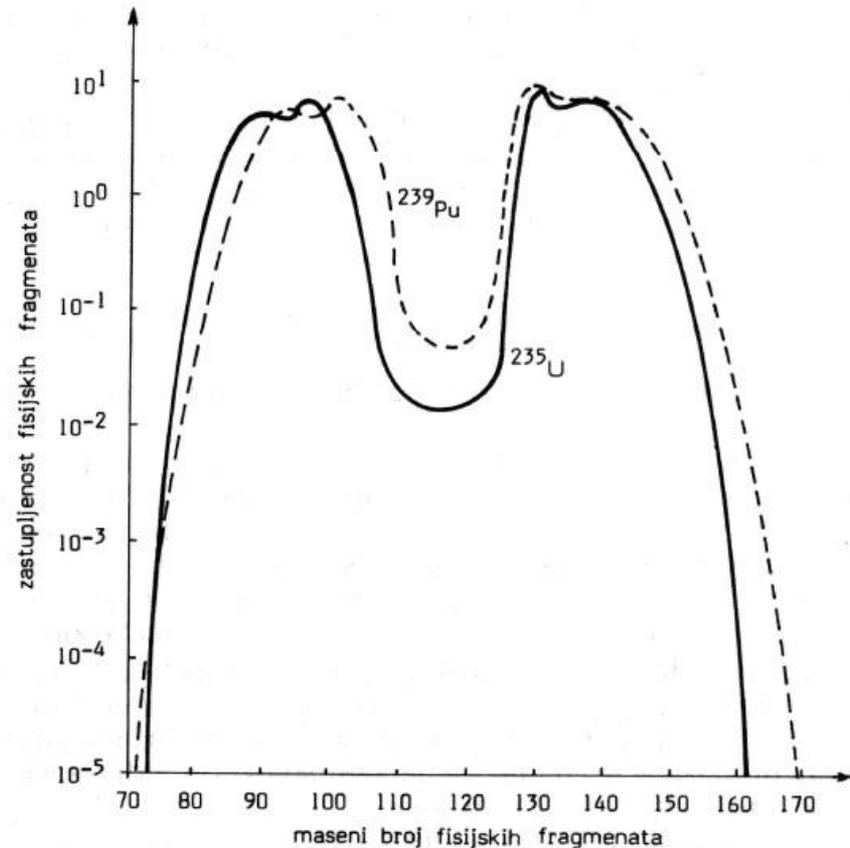
- Fisijom nastaju nova jezgra – fisijski fragmenti
- Postoji stotinjak načina na koji se teška jezgra može cijepati
- Novonastala jezgra su beta i gama radioaktivna jer imaju višak neutrona obzirom na broj protona Z
- Približno 180 MeV energije se oslobodi neposredno pri fisiji a oko 20 je posljedica radioaktivnog raspada fisijskih produkata
- Brzina osobađanja te zakašnjele energije ovisi o konstantama radioaktivnog raspada
- Radioaktivnost fisijskih produkata i pripadajuća toplina osnovni su sigurnosni problem u reaktoru
- Zaustavljanjem lančane reaktivnost ovaj izvor ne nestaje
- Neposredno nakon obustave ostatna toplina iznosi približno 6% nominalne snage na kojoj je reaktor radio
- Zbog velikog broja fisijskih produkata iznos ostatne topline uzimamo u obzir aproksimativnim relacijama

Fisijski produkti

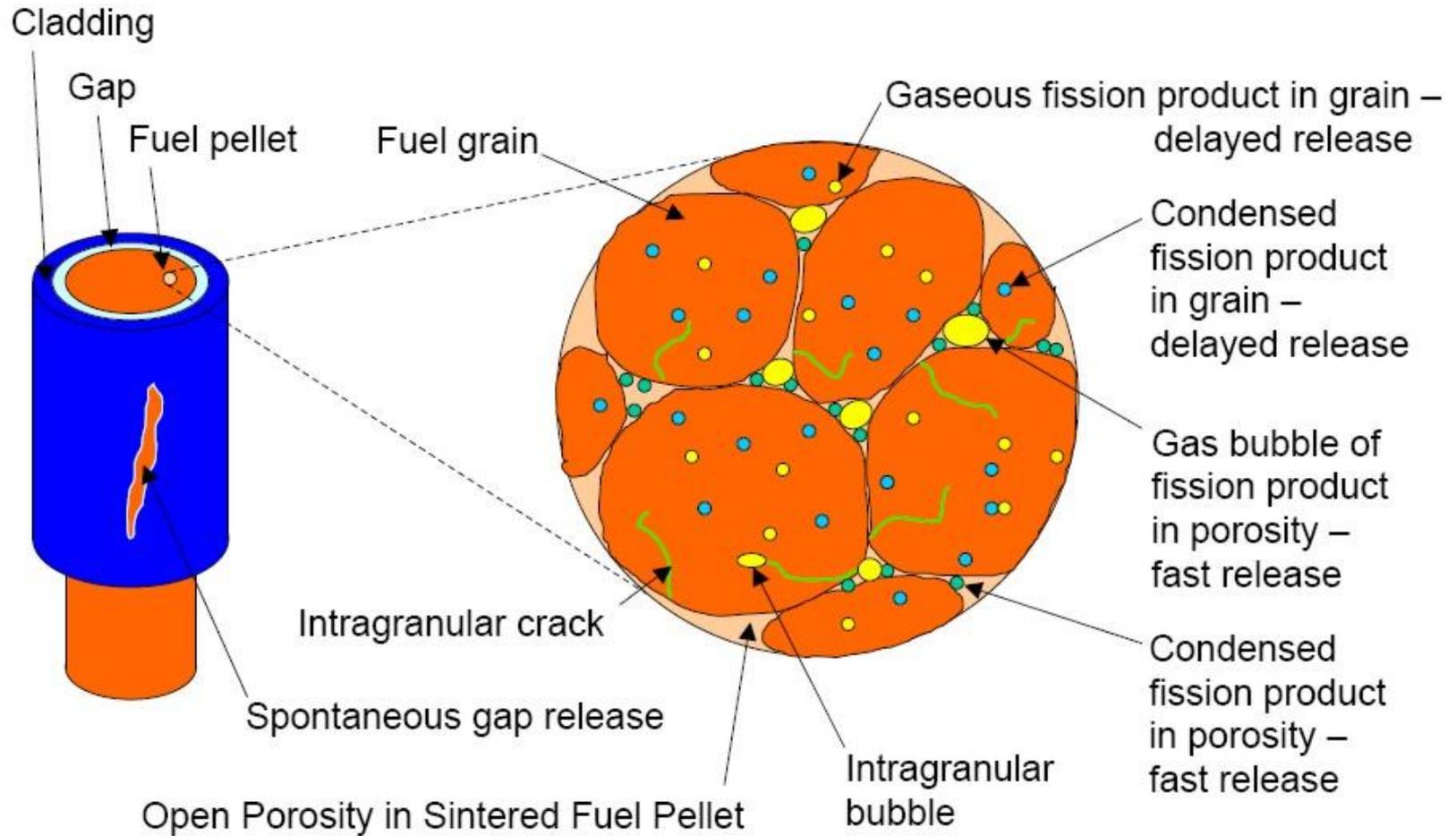
- plemeniti plinovi: Kr, Xe
- lako hlapljivi FP: I (184 C), Cs (671 C), Te ...
- srednje hlapljivi FP: Ba, La, Sr, Ru ...
- slabo hlapljivi FP: aktinidi, In, Cd ...

Ispuštanje FP u 2 faze:

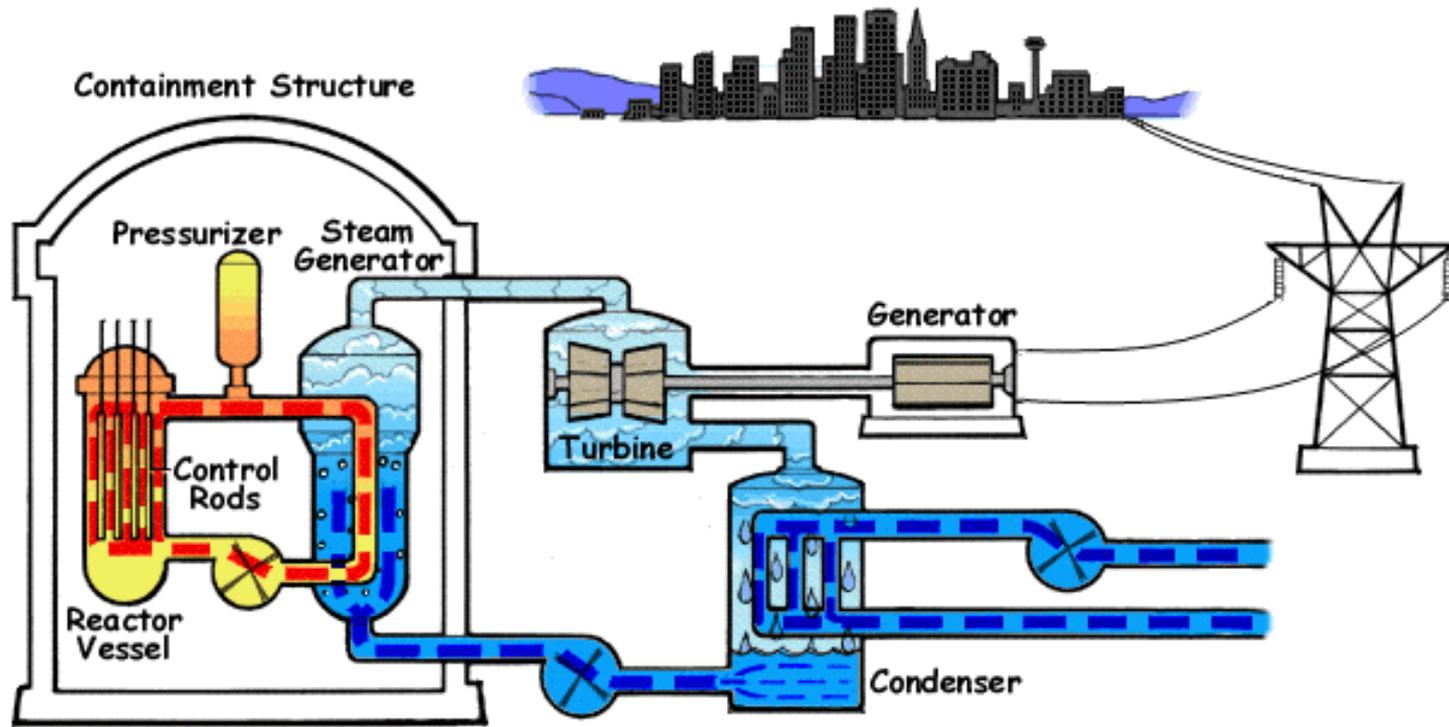
1. "gap release": ispuštanje plinovitih FP iz zazora nakon pucanja košuljice
2. nakon topljenja goriva ispuštaju se preostali plinoviti FP i lako hlapljivi FP



Fisijski produkti



NE PWR – princip rada

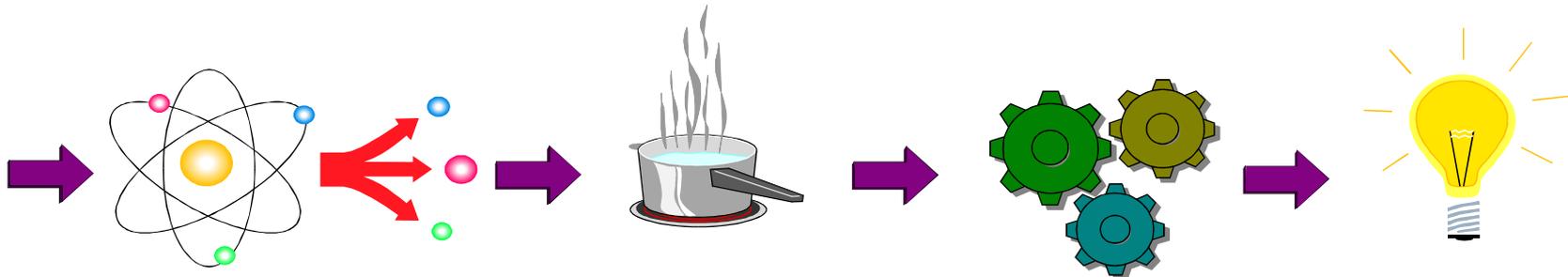


Energija fisije

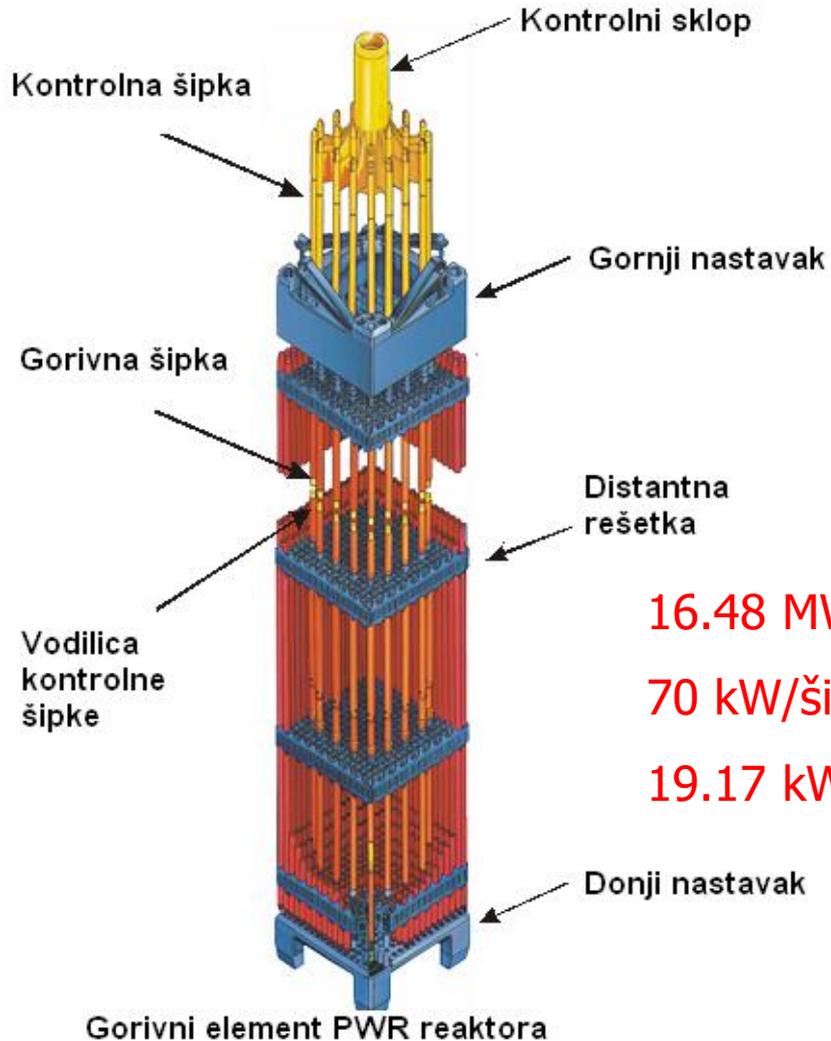
Toplinska energija

Mehanička energija

Električna energija



Gorivni element i gorivna šipka

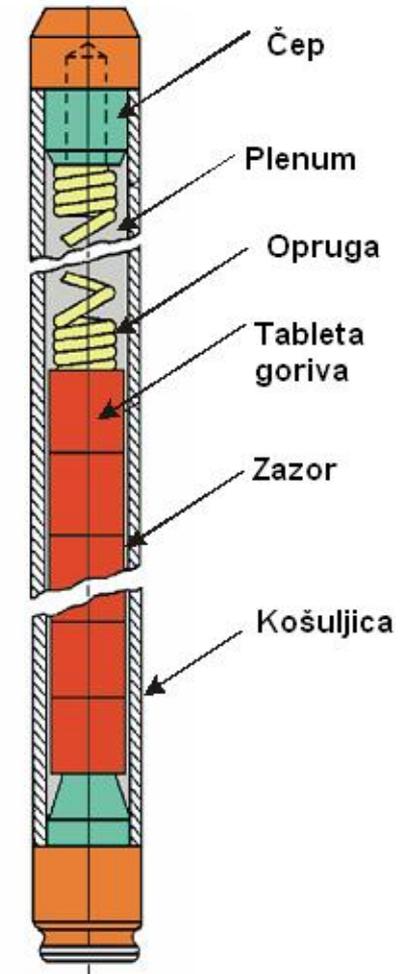


16.48 MW/FA

70 kW/šipka

19.17 kW/m

Gorivna šipka PWR reaktora



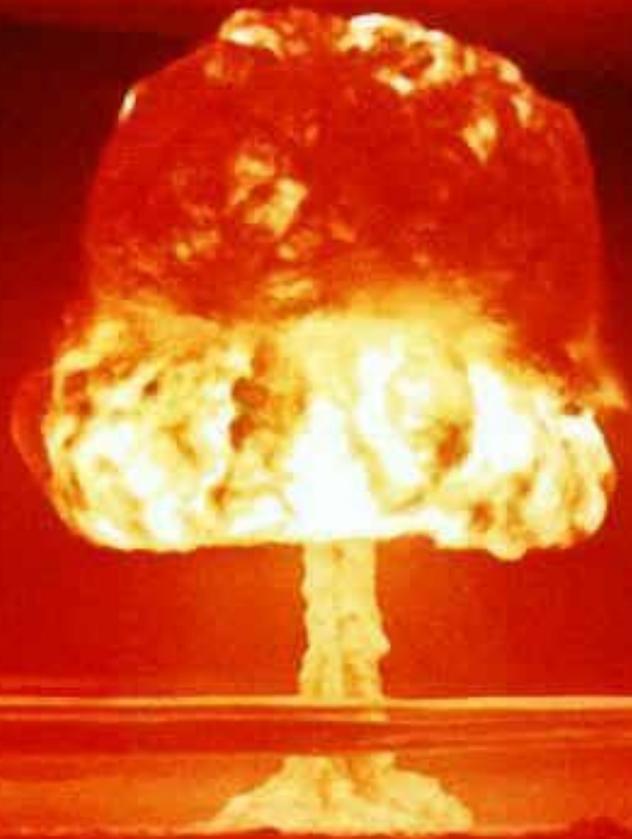
Sigurnost nuklearnih elektrana

- Zanemarive emisije u normalnom pogonu
- Konzervativan projekt s visokim stupnjem sigurnosti
- Visoki zahtjevi na kvalitetu materijala i ugradnju
- Da bi se postigao siguran pogon potrebno je:
 - *spriječiti nagle poraste snage*
 - *osigurati odvođenje ostatne topline*
 - *spriječiti ispuštanje radioaktivnog materijala*
 - *pospremiti na siguran način istrošeno gorivo*

Principi sigurnosnih mjera u nuklearnim elektranama

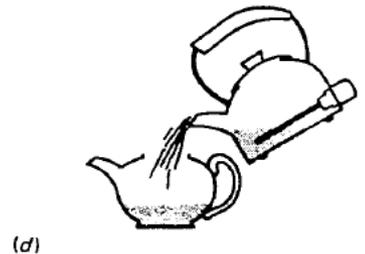
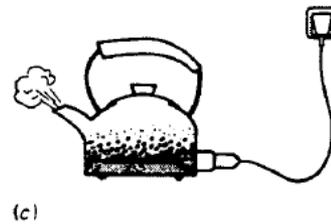
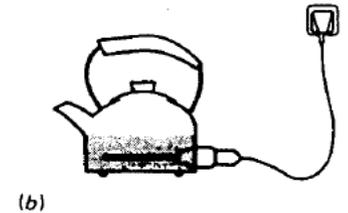
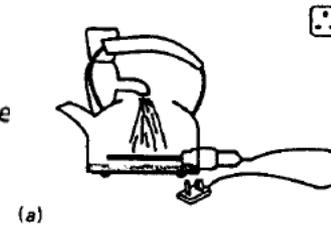
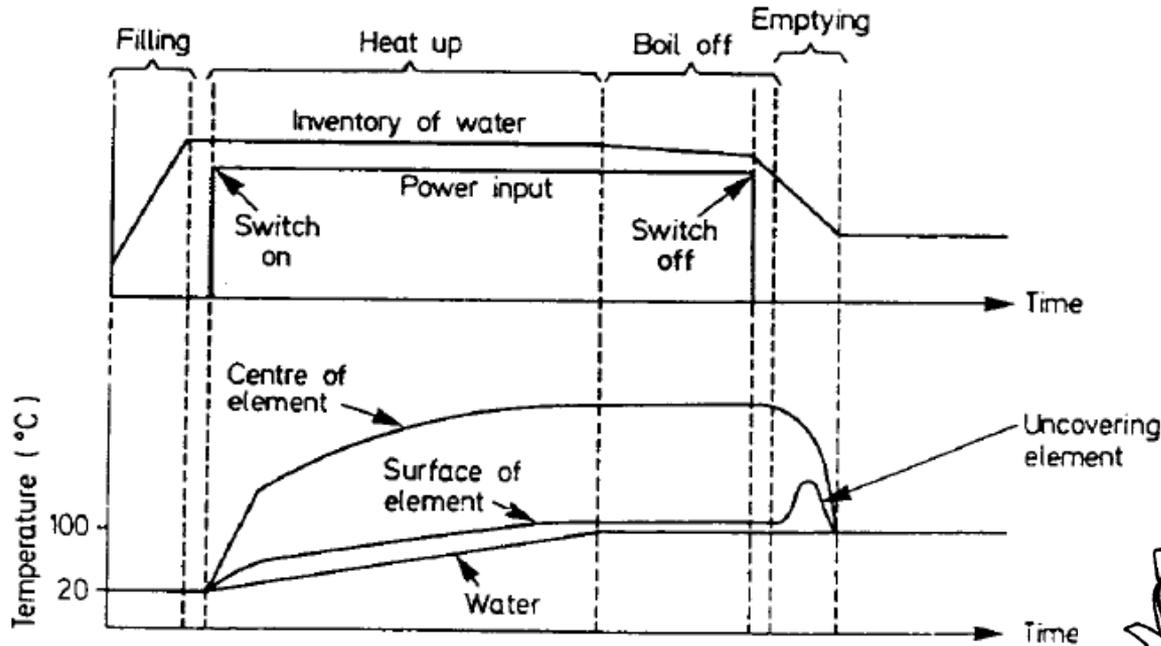
- **Nuklearna eksplozija reaktora je onemogućena projektom**
- **U svojoj jezgri nuklearni reaktor sadrži veliku količinu radioaktivnih tvari, pretežno fisijskih proizvoda.**
- **Sigurnost se u osnovi odnosi na onemogućenje širenja radioaktivnih materijala unutar postrojenja i u okoliš**
- **Do akcidentnog ispuštanja uglavnom dolazi samo ako dođe do pregrijanja goriva**
- **Sigurnost nuklearne elektrane se postiže nizom mjera u fazi projektiranja, gradnje i tijekom pogona.**

Da li je nuklearna elektrana tempirana nuklearna bomba?



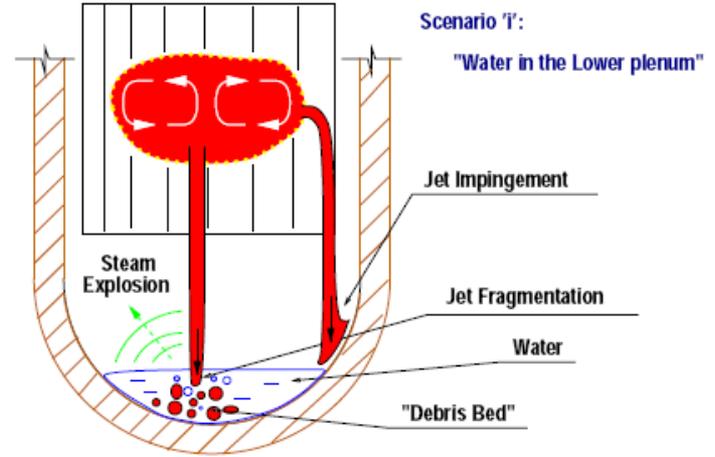
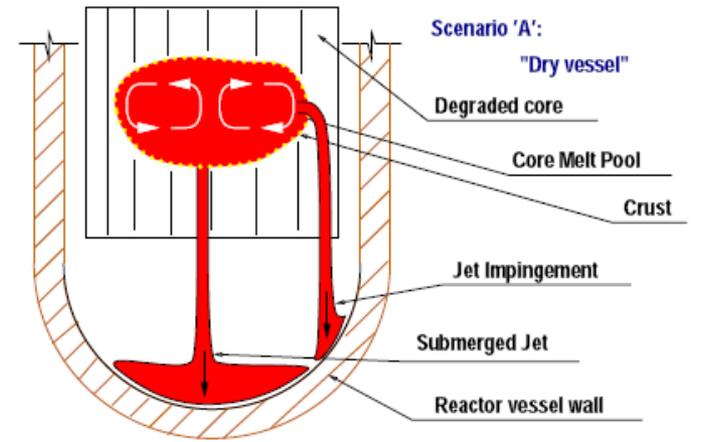
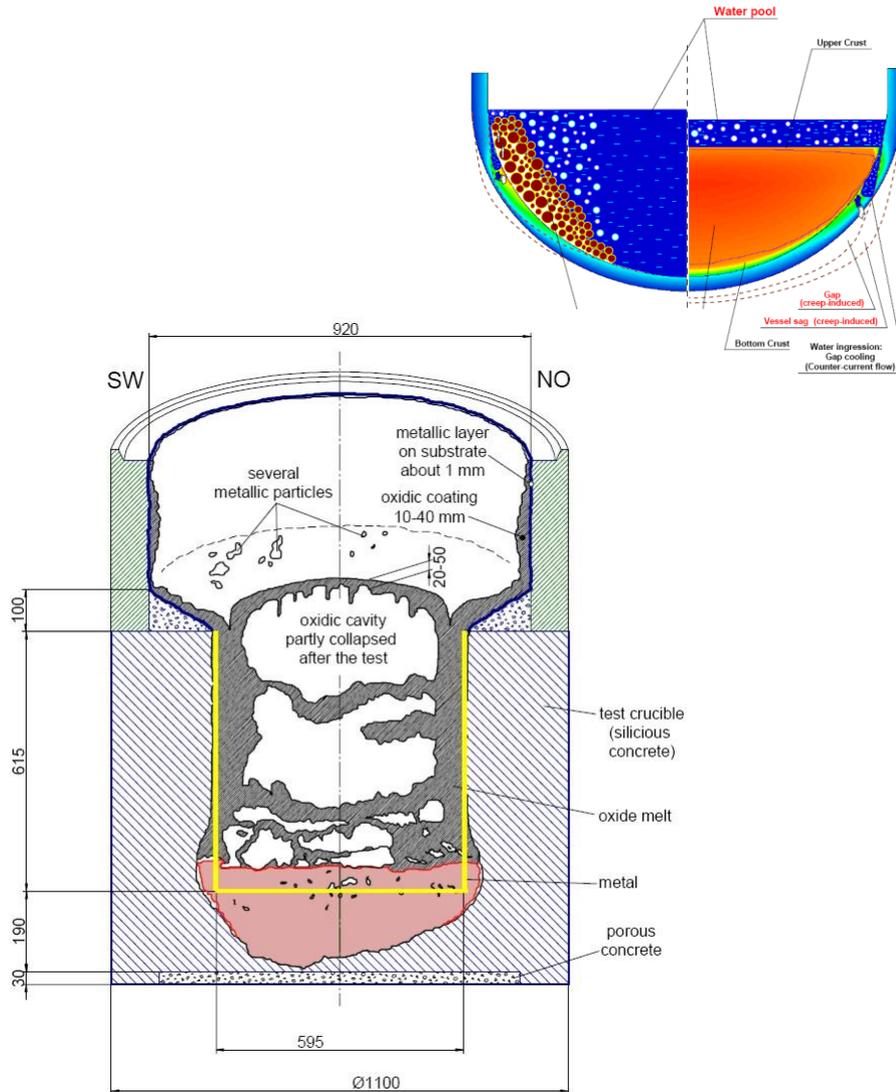
**Nuklearna eksplozija nije moguća za obogaćenje i sastav jezgre u reaktoru
Ali je potrebno spriječiti i ograničiti promptne poraste snage**

Odvođenje topline



Toplinska inercija plinskog i električnog štednjaka?

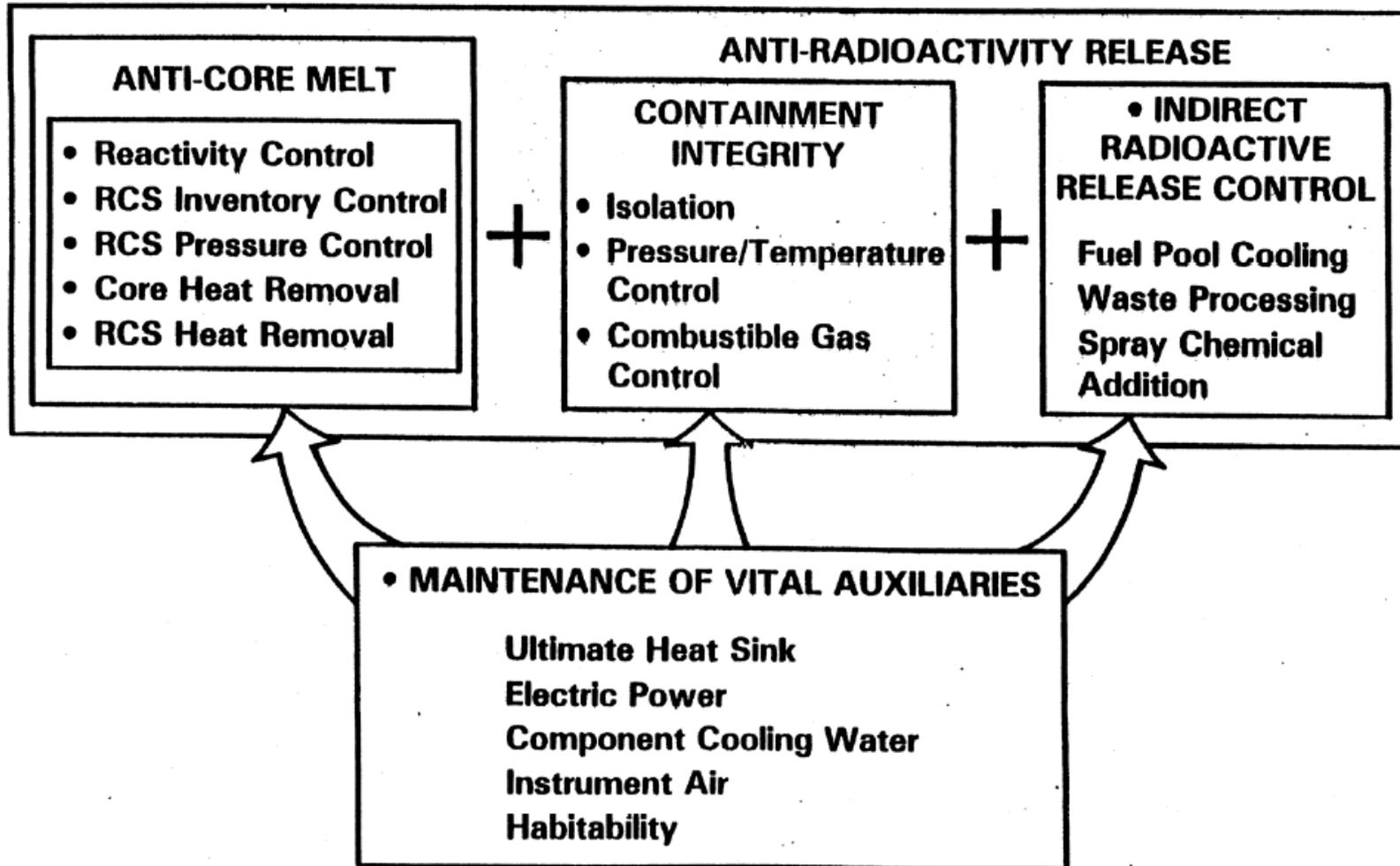
Kineski sindrom – da li je moguć?



Porast temperature jezgre obustavljen reaktor bez hlađenja

- Ostatna toplina 30 MW.
- 100,000 kg materijala u jezgri.
- Pretpostavljena srednja specifična toplina materijala jezgre 600 J/kg-C.
- Porast temperature C/s.
- Nakon 30 min srednja temperatura jezgre bi porasla 900 C.

Kritične sigurnosne funkcije



Obrana po dubini

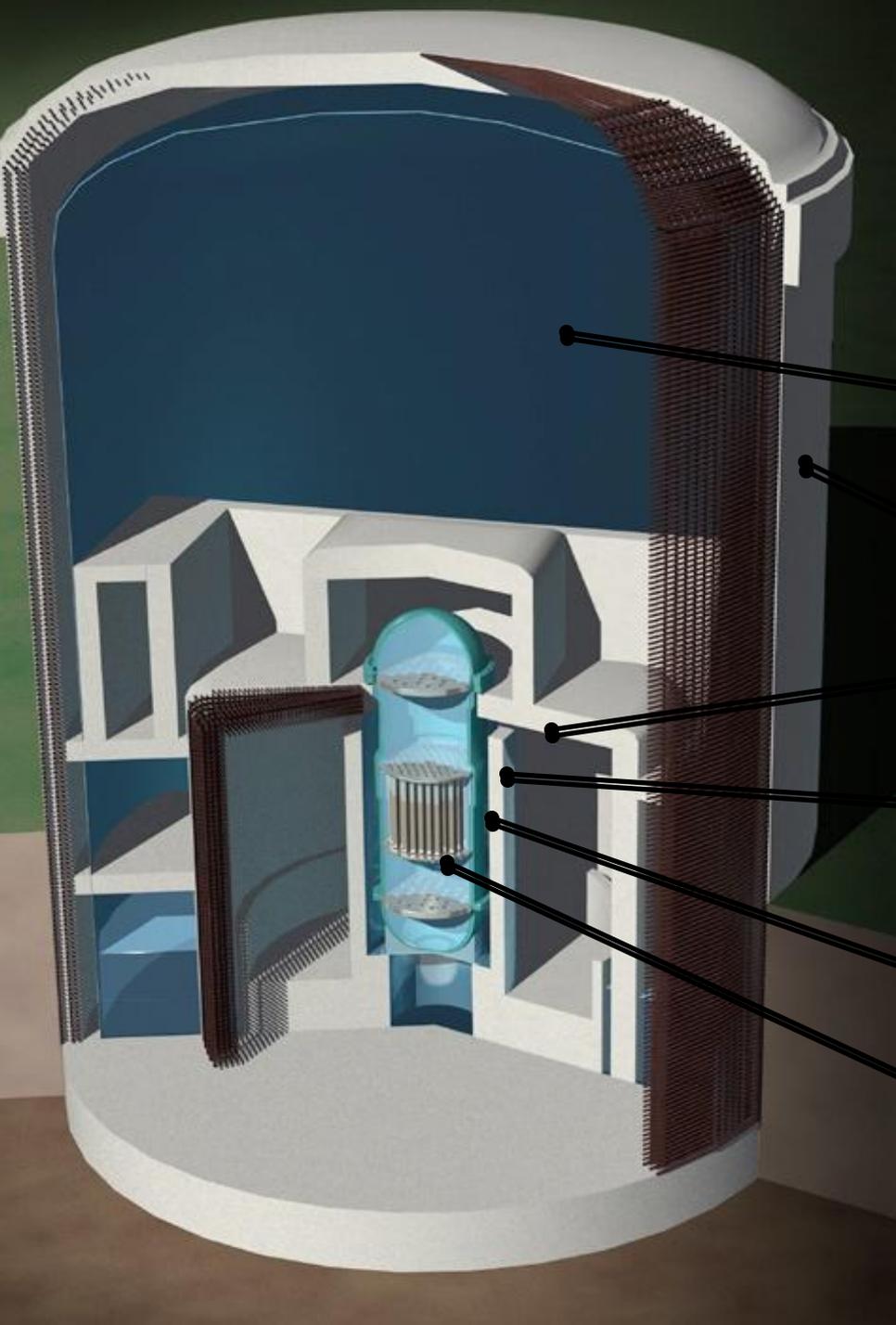
- Osnova filozofije projektiranja nuklearne elektrane sa stajališta sigurnosti je tzv. obrana po dubini.
- Obrana po dubini pretpostavlja postojanje višestrukih barijera za širenje radioaktivnosti i sigurnosnih sustava koji osiguravaju njihovu nepropusnost
- Barijere u smislu zaštite okoliša djeluju serijski, jedna nakon druge.
- Izgubljenu funkciju jednog sustava važnog za sigurnost automatski preuzima drugi.
- Bitni sustavi su u najmanju ruku udvojeni
- Sustavi mogu biti aktivni ili pasivni (kako dobivaju energiju potrebnu za izvršavanje sigurnosne funkcije)
- Barijere možemo razmatrati kao stvarne fizičke barijere ugrađene u nuklearnu elektranu i kao fizičke i administrativne mjere koje se poduzimaju u nuklearnoj elektrani za zaštitu tih barijera.

Obrana po dubini

- **Fizičke barijere su:**
 - matrica nuklearnog goriva
 - obloga gorivnog elementa
 - primarni rashladni krug
 - zaštitna posuda (kontejnment)

- **Tehnički sustavi koji osiguravanju funkciju fizičkih barijera:**
 - sustav za zaštitno hlađenje jezgre reaktora (štiti gorivne elemente od pregrijanja)
 - sustav za ograničavanje porasta tlaka u kontejnmentu (štiti zaštitnu posudu od previsokog tlaka i temperature)

Višeslojna zaštita



Kontejnmentska posuda

4 cm čelika

Kontejnmentska zgrada

1 m prenapregnutog betona

Unutrašnja betonska struktura

1.5 m prenapregnutog betona

Biološki štit

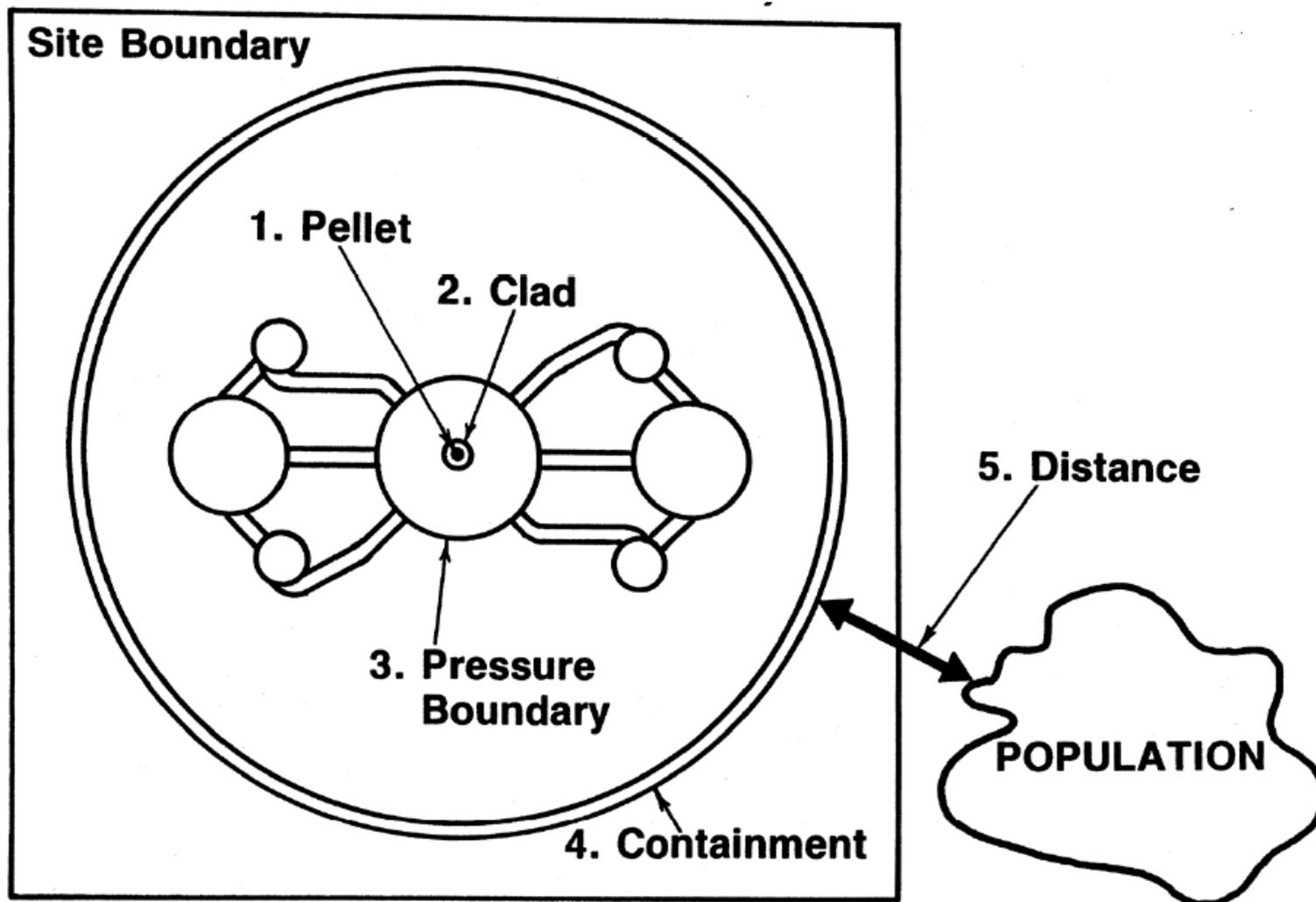
1,2 m teškog betona +
4 cm čelika

Reaktorska posuda

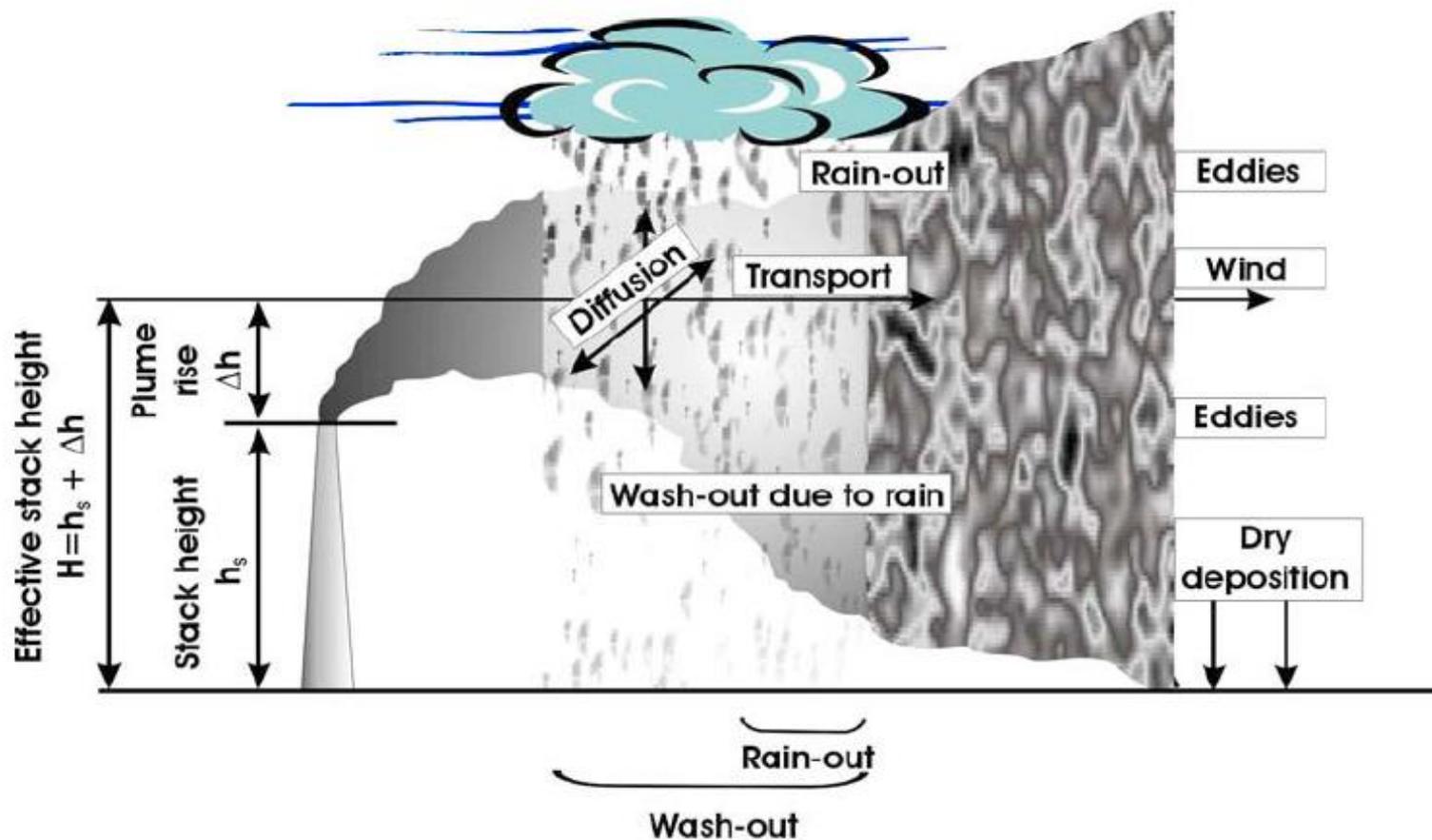
20 cm čelika

Matrica goriva + košuljica

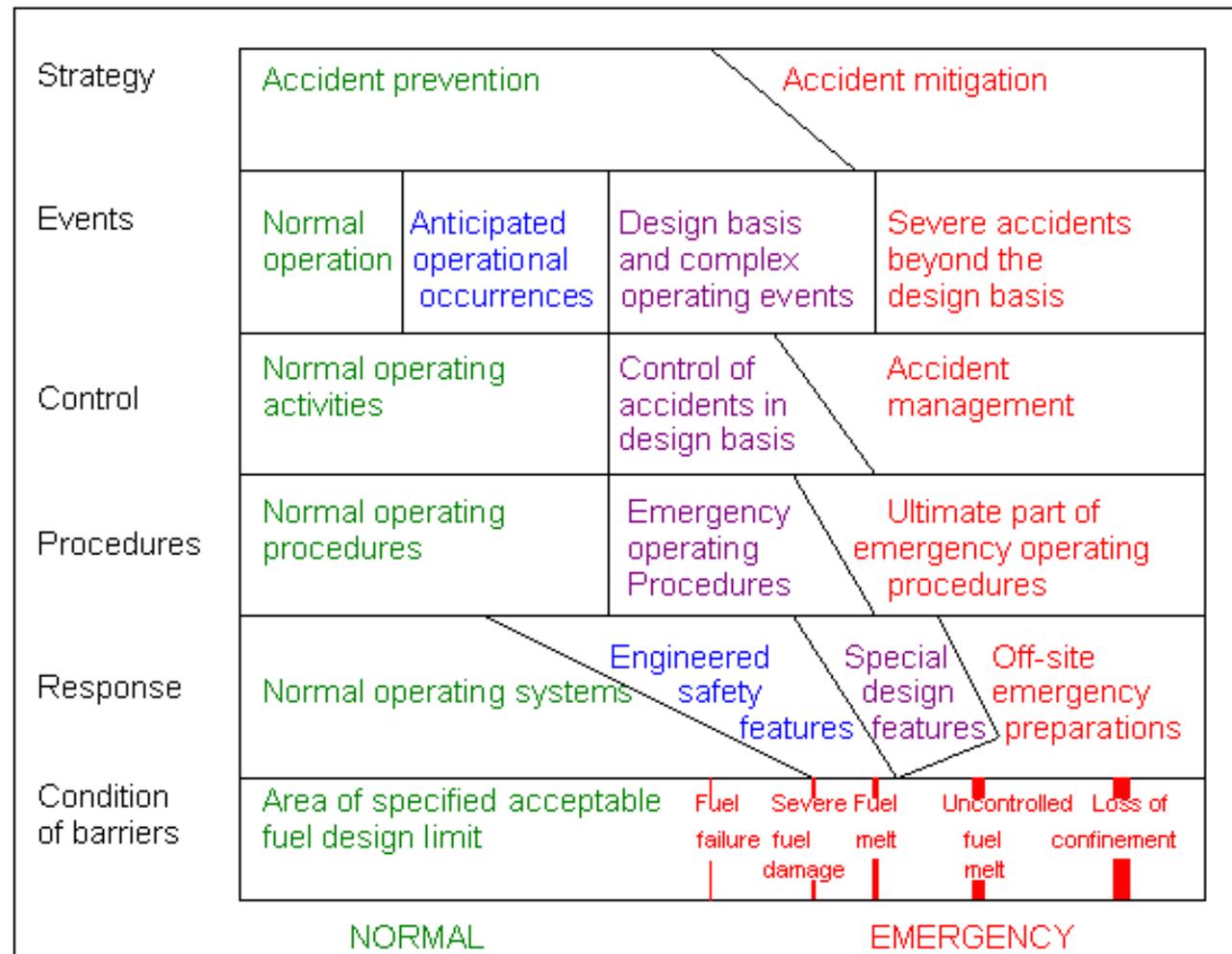
Prostorni aspekt obrane po dubini



Ponašanje efluenata oslobođenih u atmosferu



Ideja obrane po dubini

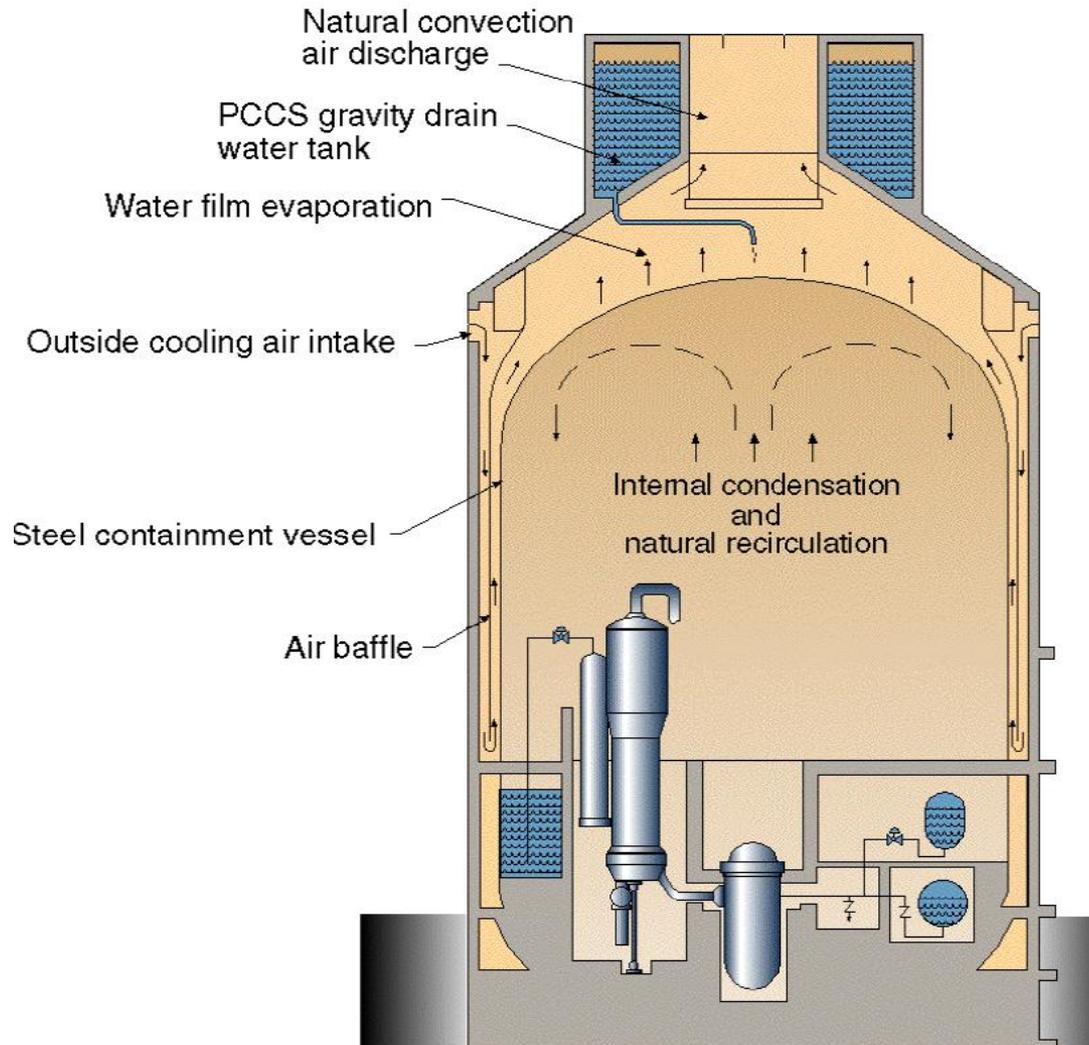


Principi projektiranja sigurnosnih sustava

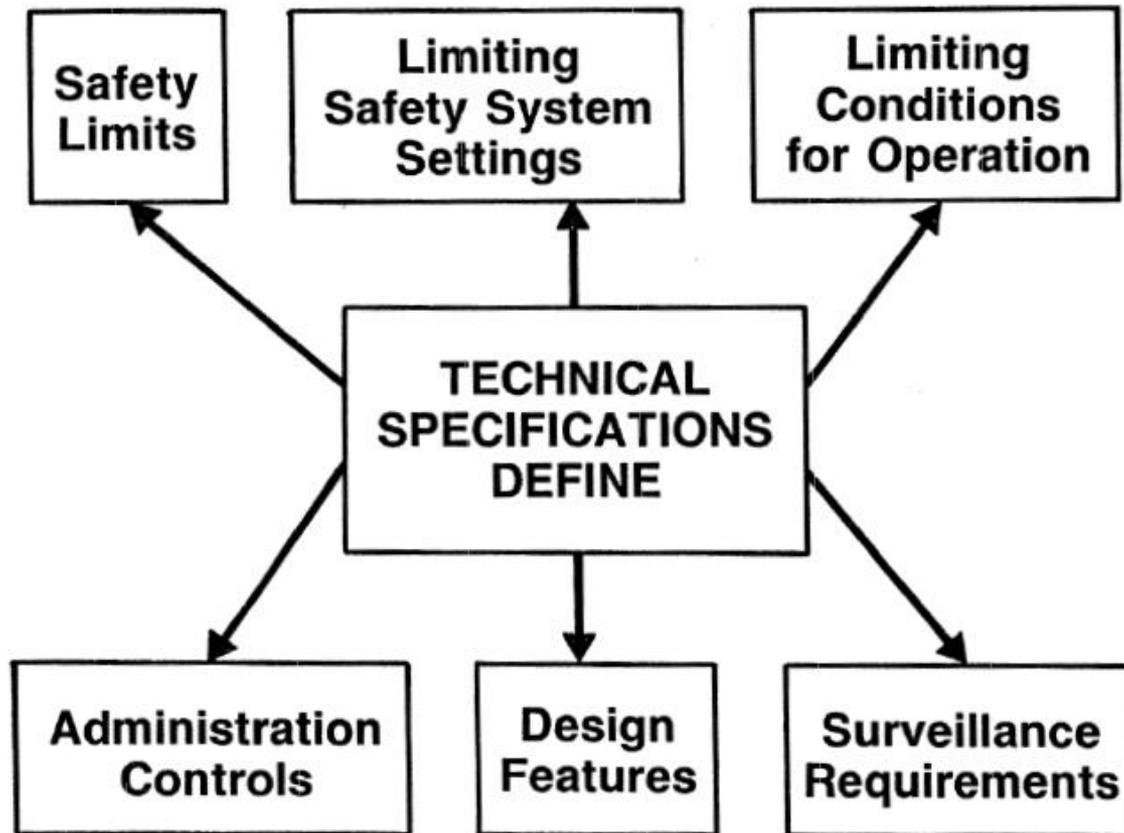
- Jednostruki otkaz
- Redundantnost
- Diverzitet
- Neovisnost sustava
- Fizička separacija
- Common cause greške
- Sigurni smjer greške
- Provjera stanja sustava
- Aktivna i pasivna sigurnost

Pasivni sigurnosni sustavi

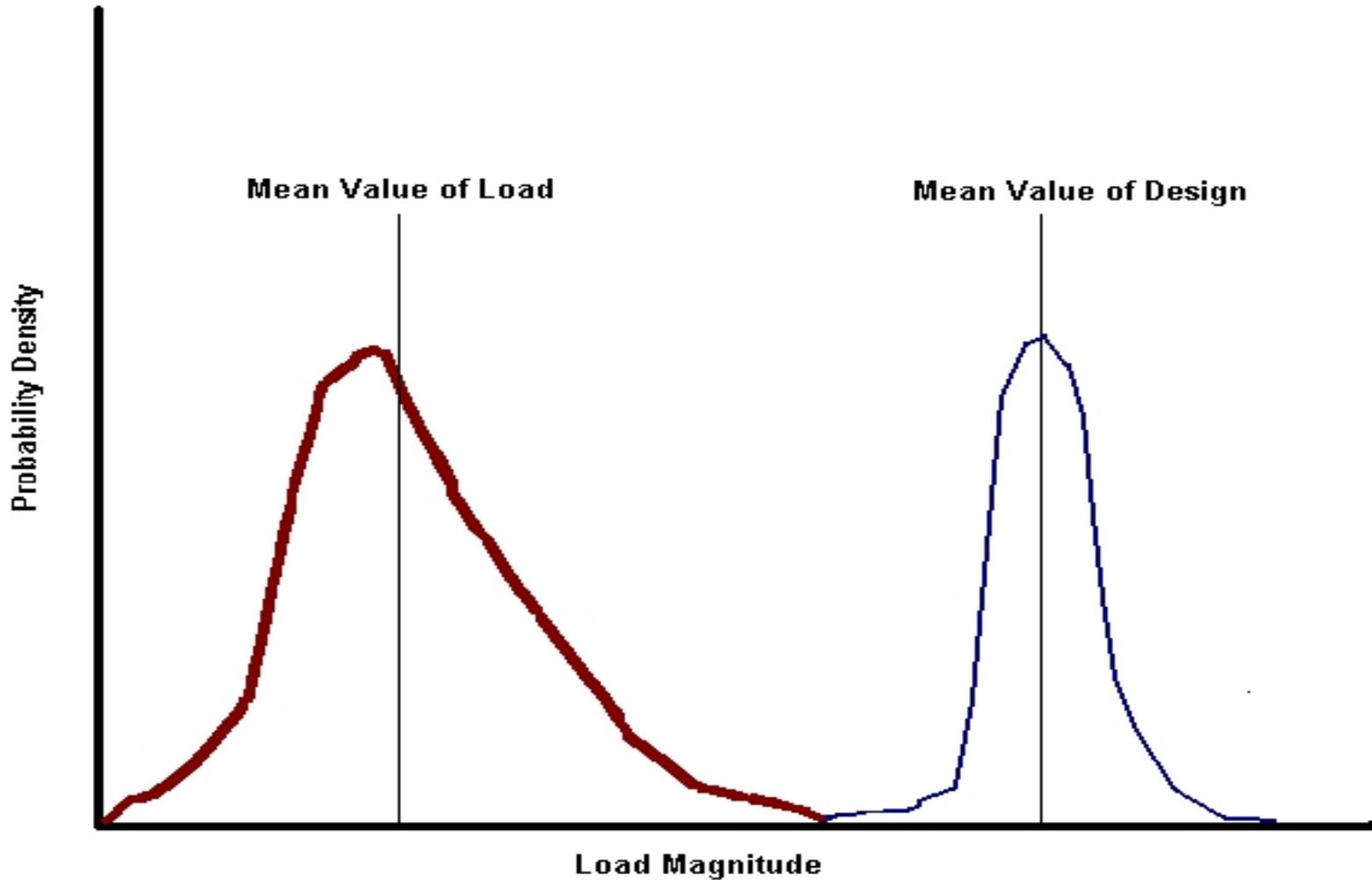
Primjer AP1000



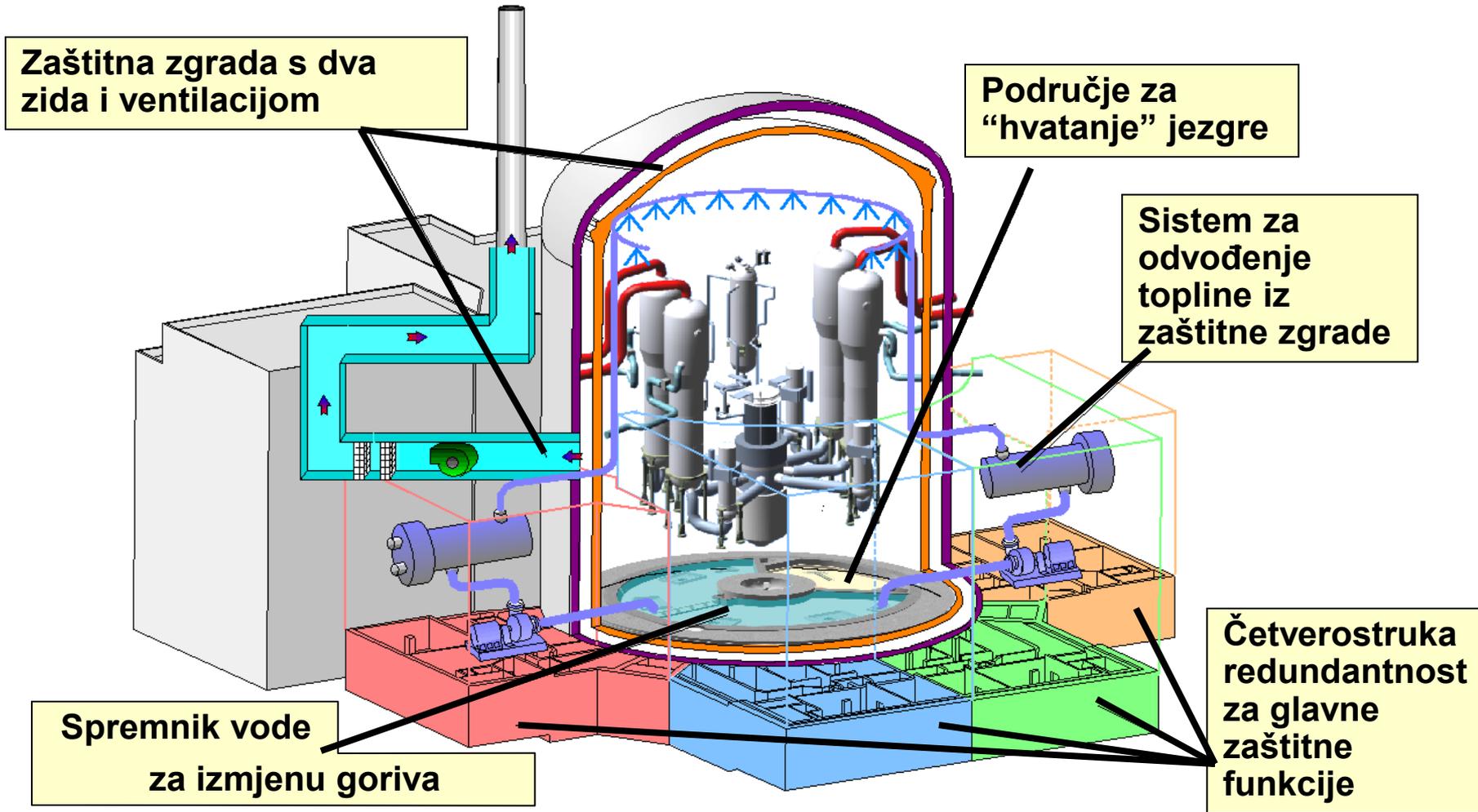
Sigurnosni limiti i postavne vrijednosti



Projektne margine



Evolutivni PWR – EPR



Analize sigurnosti elektrane

- Cilj je demonstrirati da NE može biti u pogonu bez nepotrebnog rizika za zdravlje ljudi i sigurnost
- Aplikacija za pogonsku dozvolu uključuje dokumentirano stanje sigurnosti elektrane - sigurnosni izvještaj elektrane (Final Safety Analysis Report - FSAR)
- Sigurnosni izvještaj mora sadržavati analizu projekta i pogonskih svojstava elektrane da se pokaže postojanje sigurnosnih margina za sve relevantne sigurnosne limite za vrijeme normalnog pogona, tranzijenata i projektnih akcidenata za cijelo vrijeme života elektrane

Događaji od značaja za sigurnost

- Svrha evaluiranja širokog spektra događaja u sigurnosnim analizama je da se ocjene sva pogonska stanja elektrane i da se demonstrira suglasnost s regulatornim zahtjevima i uvjetima navedenim u pogonskoj dozvoli
- Da se osigura sustavan pristup koristi se kategorizacija događaja po frekvenciji pojavljivanja, težini posljedica i prirodi poremećaja

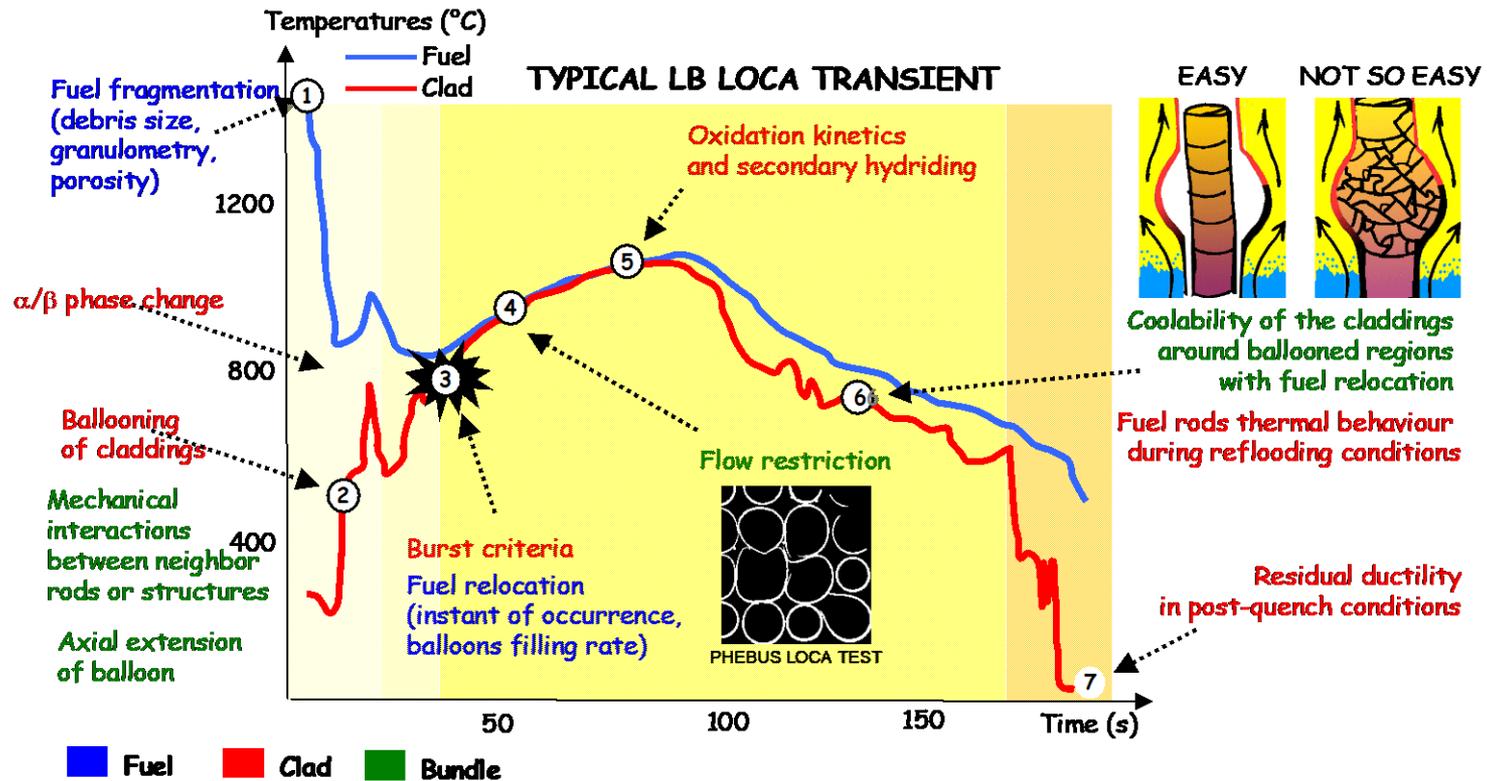
Unutarnji i vanjski inicirajući događaji

1. **Normalni pogon**
2. **Očekivani pogonski događaji**
(frekvencija veća od $1e-2$ /god)
3. **Projektne nesreće (DBA)**
(frekvencija $1e-2$ do $1e-5$ /god)
4. **Izvan projektne (BDBA) i teške nesreće**
(frekvencija $1e-4$ do $1e-5$ /god CDF
frekvencija $1e-5$ do $1e-6$ /gof LRF)

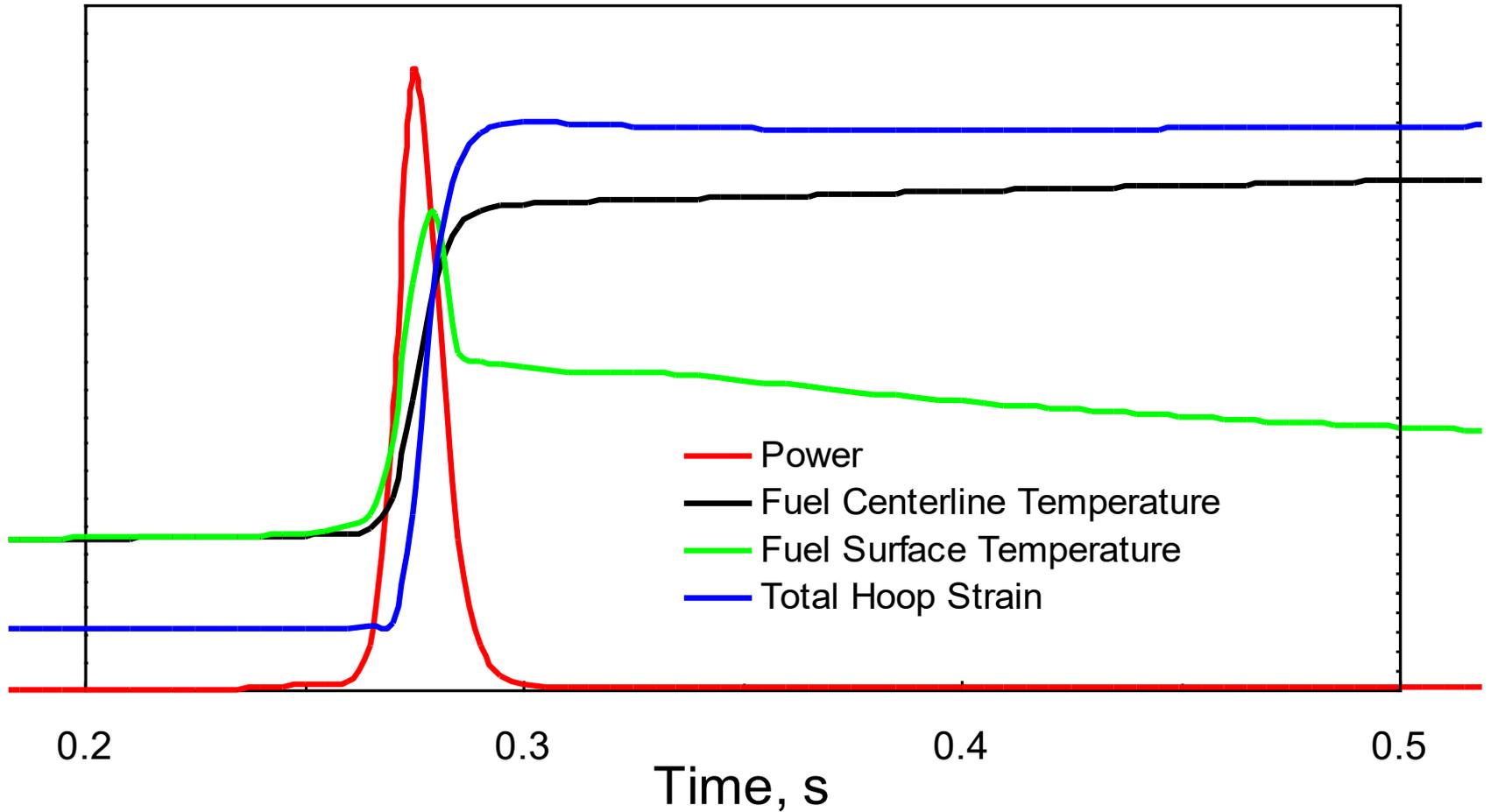
Funkcionalna klasifikacija događaja

- 1. Increase In Heat Removal By The Secondary System**
- 2. Decrease In Heat Removal By The Secondary System**
- 3. Decrease In Reactor Coolant System Flow Rate**
- 4. Reactivity And Power Distribution Anomalies**
- 5. Increase In Reactor Coolant Inventory**
- 6. Decrease In Reactor Coolant Inventory**
- 7. Radioactive Release From A Subsystem Or Component**
- 8. Component**
- 9. Anticipated Transients Without Scram**

Typični LOCA odziv



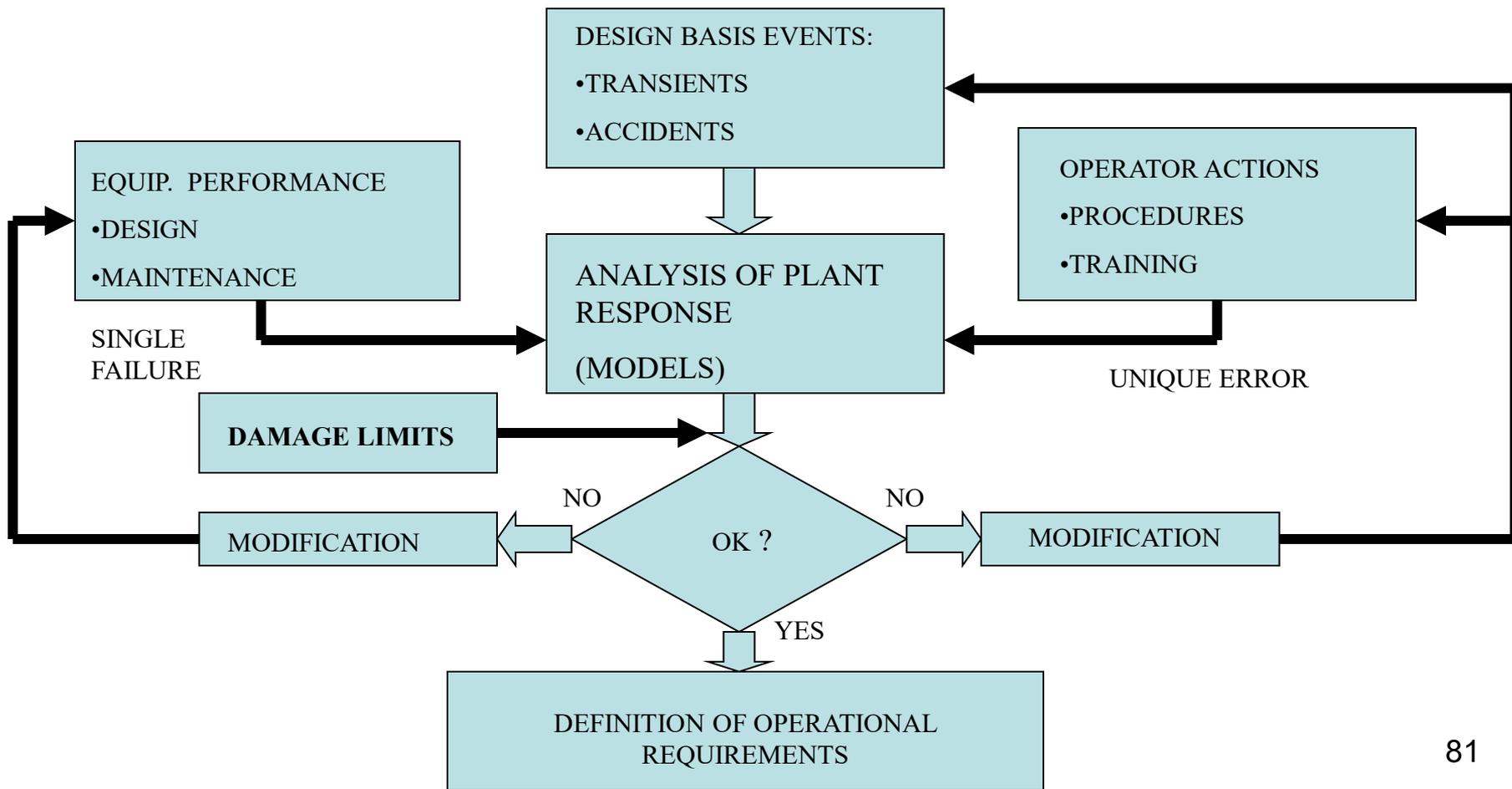
Typični RIA odziv



Kvantitativni kriteriji prihvatljivosti

- **FUEL TEMPERATURE**
- **FUEL ENERGY DEPOSITION**
- **CLAD HEAT TRANSFER**
- **CLAD TEMPERATURE**
- **CLAD INTEGRITY**
- **RADIOACTIVITY IN COOLANT**
- **PRIMARY OR SECONDARY SYSTEM PRESSURE**
- **CONTAINMENT PRESSURE**
- **RADIOACTIVITY IN CONTAINMENT**
- **DOSE IN CONTAINMENT**
- **DOSE TO SITE WORKERS**
- **DOSE AT SITE BOUNDARY**
- **DOSE IN LOW POPULATION ZONE**
- **DOSE TO THE PUBLIC**
- **PUBLIC HEALTH EFFECTS**

Analyze sigurnosti - determinističke



Level 1 PSA

Analysis of Core Damage Frequency

- Postulated initiating events
- Specification of safety system requirements
- Analysis of the event sequence
- Safety system failure analysis
- Data
- CCF (Common Cause Failures)
- HRA (Human Risk Assessment)
- Quantification of the analysis
- Results of the analysis of core damage frequency

Level 2 PSA

Analysis of Accident Progression from Core Damage to Release of Radioactive Material

- Definition of plant damage states
- Modelling of core damage progression
- Data
- Containment performance analysis
- Source term analysis
- Results of level 2 PSA
- On-site accident management

Level 3 PSA

Analysis of the Off-site Consequences

- Source term grouping
- Atmospheric dispersion modelling
- Meteorological data
- Population, Agricultural and Economic data
- Results of the societal risk estimates
- Off-site emergency planning

Probabilistički sigurnosni pokazatelji

- Definiranje kriterija
- Numeričke vrijednosti
- Jedna od rijetkih industrija koja je prihvatila kvantitativne pokazatelje sigurnosti

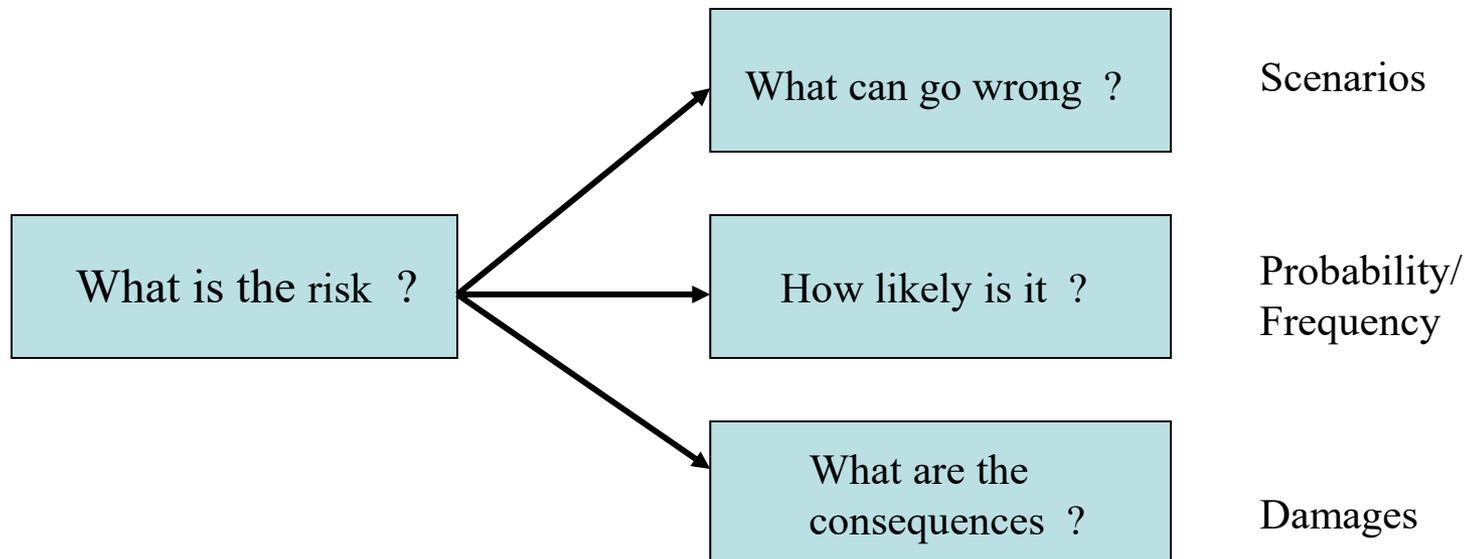
	CDF	Large releases
Existing NPP	10^{-4}	10^{-5}
New NPP	10^{-5}	10^{-6}

Rizik vezan za nuklearne elektrane

Analize rizika

- **Determinističke i probabilističke analize su komplementarne**
- **Cilj je odrediti rizik od pogona nuklearnih elektrana**

RIZIK:



How Does Risk Assessment Work?

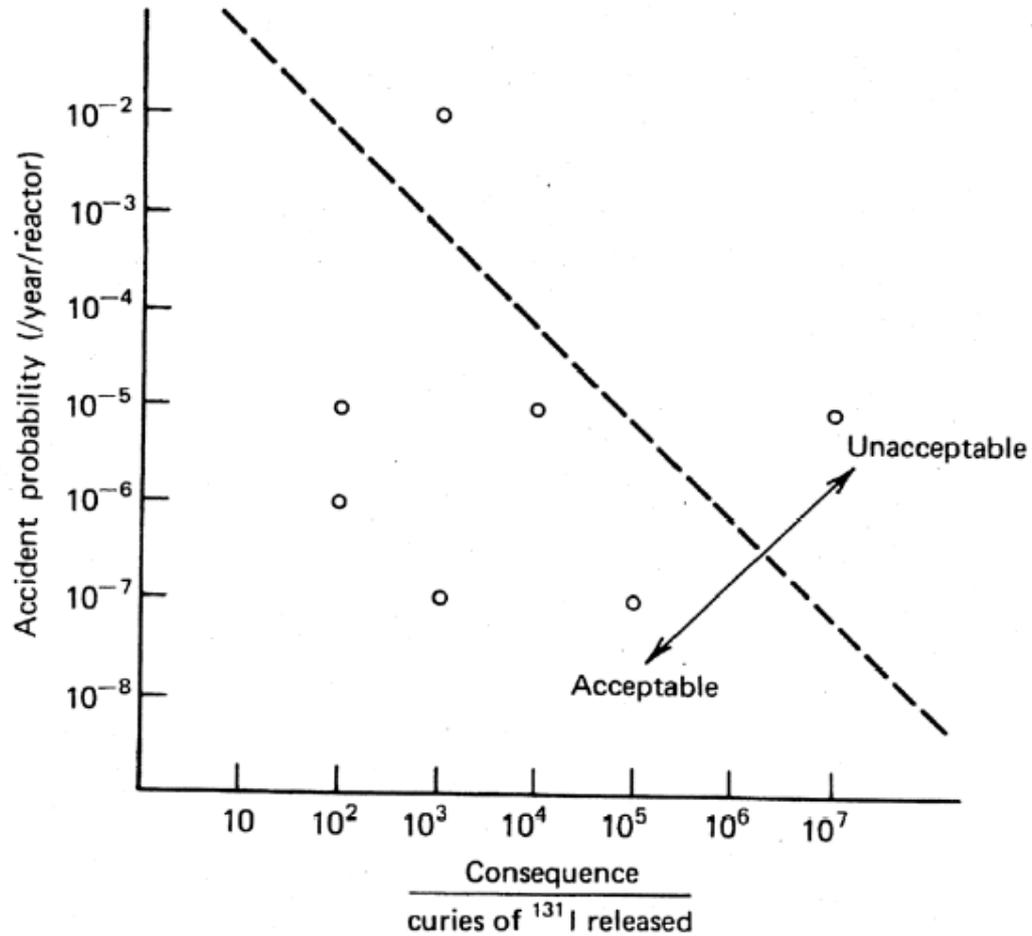
- What are the risks from driving an automobile?
- There are 15,000,000 accidents per year, 1 in 300 of which result in death, there are 250,000,000 people

$$\textit{Societal Risk} = 15,000,000 \frac{\textit{accidents}}{\textit{year}} \times \frac{1}{300} \frac{\textit{deaths}}{\textit{accidents}} = 50,000 \frac{\textit{deaths}}{\textit{year}}$$

$$\textit{Individual Risk} = \frac{50,000 \textit{ deaths / year}}{250,000,000 \textit{ people}} = 2 \times 10^{-4} \frac{\textit{deaths}}{\textit{person} \cdot \textit{year}}$$

$$\textit{Lifetime Risk} = 2 \times 10^{-4} \frac{\textit{deaths}}{\textit{person} \cdot \textit{year}} \times 70 \textit{ years} = 0.014 (1 \textit{ in } 70)$$

Farmerov model rizika



Attitudes Towards Risk

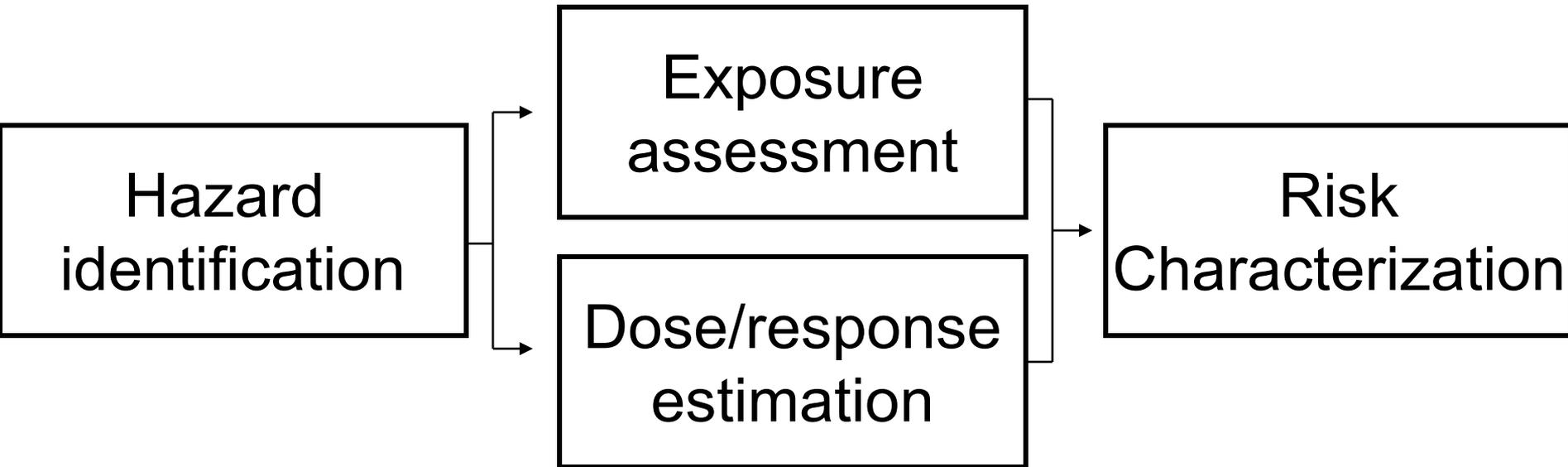
- High Risk Activities are usually on the order of the Disease Mortality Rate :
 10^{-2} deaths/(person-yr)
- Low Risk Activities are usually on the order of the Natural Hazards Mortality Rate:
 10^{-6} deaths/(person-yr)

Acceptability

- Acceptability Towards Risk depends on:
 - Benefits of Activity
 - Voluntary Nature of Activity
 - Perception
 - Consequence Distribution
- Consequence Distribution:
 - Given two activities with equal risk, the public will tend to accept Low Consequence-High Frequency Events more readily than High Consequence-Low Frequency Events.

- Malignant neoplasm second leading cause of death
- Rate of 182.7 deaths per 100,000 people /a
- Average person's risk of dying from cancer is 2×10^{-3} per year ($\sim 15\%$ over 75-years)
 - 100 person-Sv $\Rightarrow \sim 5$ fatal cancers
 - "Averaged" risk of 5×10^{-2} fatal cancers per Sv
 - Equivalent dose is 0.04 Sv per year per person

Risk Assessment



- Hazard identification uses toxicology (cell, tissue and animal tests) and epidemiology (population data and field samples)
- Exposure assessment includes determination of sources, environmental concentrations, exposure, dose, and uncertainties

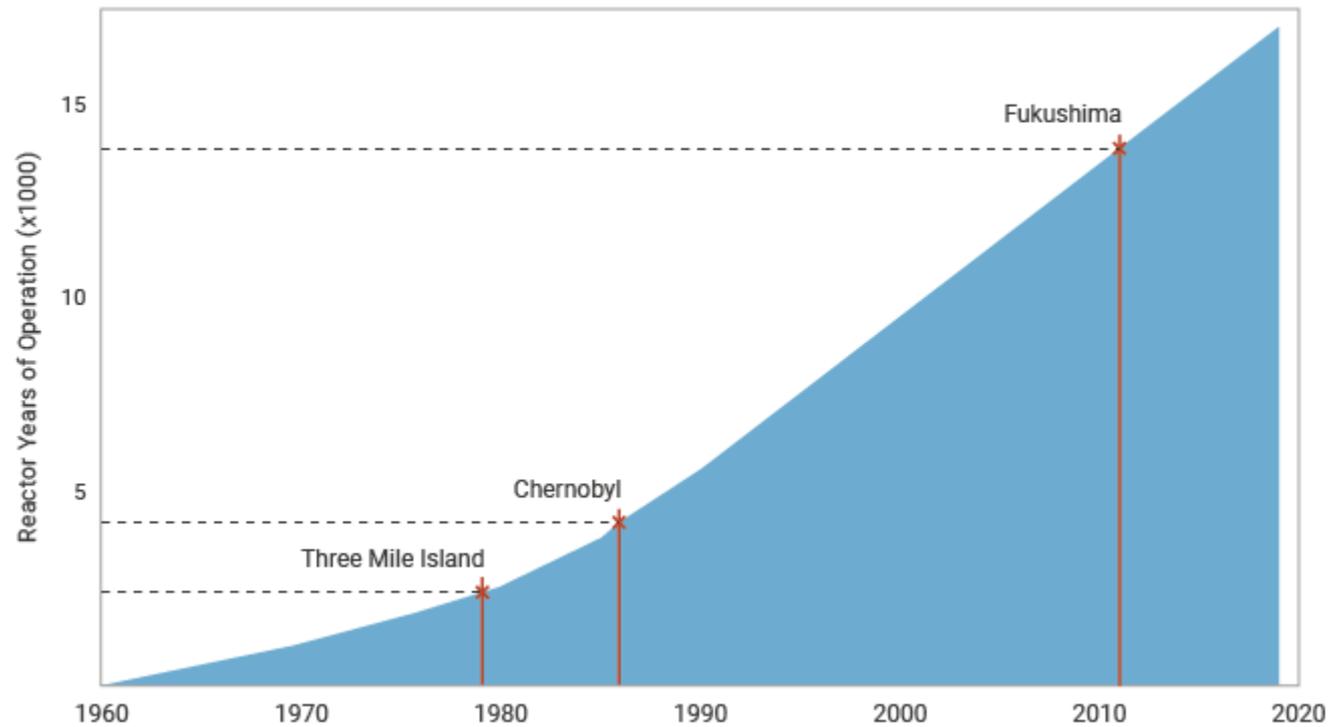
Nuklearne nesreće

Nuklearne nesreće

- **Da** li su moguće?
- **Da** li ih je bilo?
- Kako je do njih došlo?
 - Greške projektu
 - Greške u procedurama
 - Greške u treningu
 - Greške operatora u izvedbi
- Koji je dugoročni efekt?
 - Nuklearne elektrane su došle na loš glas koji prati nuklearnu energiju vezano za njene vojne početke
 - S druge strane unaprijedile su sigurnost (bolji projekti, procedure, školovanje, planiranje)

Kumulativno vrijeme pogona

Cumulative Reactor Years of Operation



Teške reaktorske nesreče eksperimentalni

Reactor	Date	Immediate Deaths	Environmental effect	Follow-up action
NRX, Canada (experimental, 40 MWt)	1952	Nil	Nil	Repaired (new core) closed 1992
Windscale-1, UK (military plutonium- producing pile)	1957	Nil	Widespread contamination. Farms affected (c 1.5 x 10¹⁵ Bq released)	Entombed (filled with concrete) Being demolished.
SL-1, USA (experimental, military, 3 MWt)	1961	Three operators	Very minor radioactive release	Decommissioned
Fermi-1 USA (experimental breeder, 66 MWe)	1966	Nil	Nil	Repaired, restarted 1972
Lucens, Switzerland (experimental, 7.5 MWe)	1969	Nil	Very minor radioactive release	Decommissioned

Teške reaktorske nesreče komercijalni

Reactor	Date	Immediate Deaths	Environmental effect	Follow-up action
Browns Ferry, USA (commercial, 2 x 1080 MWe)	1975	Nil	Nil	Repaired, it took 18 months
Three-Mile Island-2, USA (commercial, 880 MWe)	1979	Nil	Minor short-term radiation dose (within ICRP limits) to public, delayed release of 2×10^{14} Bq of Kr-85	Clean-up program complete, in monitored storage stage of decommissioning
Saint Laurent-A2, France (commercial, 450 MWe)	1980	Nil	Minor radiation release (8×10^{10} Bq)	Repaired, (Decomm. 1992)
Chernobyl-4, Ukraine (commercial, 950 MWe)	1986	31 staff and firefighters	Major radiation release across E.Europe and Scandinavia (11×10^{18} Bq)	Graphite fire Entombed
Vandellos-1, Spain (commercial, 480 MWe)	1989	Nil	Nil	Turbine fire after 17 years of operation Decommissioned due to uneconomic repair

Windscale pile

- October 10, 1957 UK
- Vojno postrojenje za proizvodnju Pu, grafitom moderirano i direktno hladeno zrakom
- Grafit aneling + oštećenje goriva + vatra
- Gašenje je trajalo 3 dana
- INIS level 5 release



Browns Ferry Fire



Browns Ferry Fire

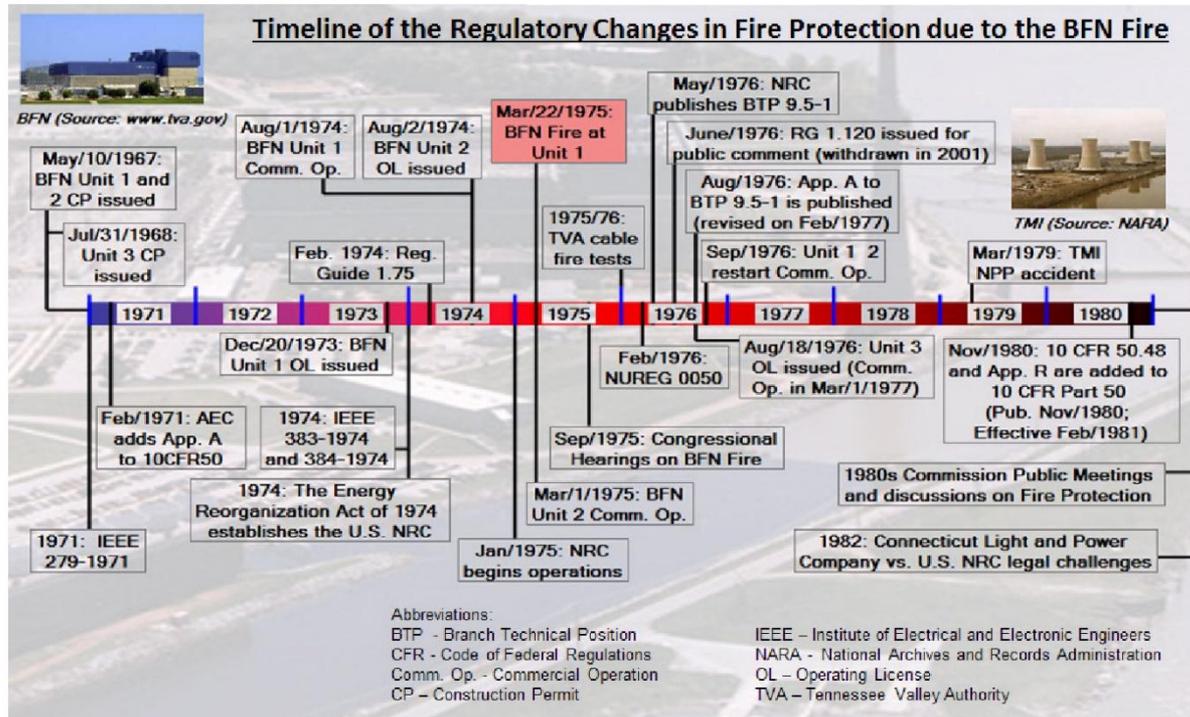
- The March 22, 1975, fire at the Browns Ferry Nuclear Power Plant (near Decatur, Ala.) fundamentally changed how the NRC dealt with fire protection at U.S. nuclear power plants. Plant workers accidentally started the fire when checking fire barrier penetration seals for leaks in the room where electric cables entered the reactor building. The workers used a lit candle to check for air leaks. An air leak caused the candle flame to ignite both seal material and the cables passing through it.
- **Firefighters extinguished the fire almost seven hours later. More than 1,600 electrical cables were affected, 628 of which were important to plant safety. The fire damaged cables for power, control systems and instrumentation, affecting reactor safety systems. The fire-damaged cables prevented operators from monitoring the plant normally. Operators had to perform emergency repairs on fire- affected systems in order to shut the reactor down safely.**
- **Investigations after the fire revealed shortcomings in both the plant's fire protection designs and its procedures for responding to a fire. The event demonstrated that a fire in certain locations at a nuclear plant could damage redundant safety systems and components, making it difficult to shut the reactor down safely.**

Browns Ferry Fire

- Cable spreading area privremeno brtvljenje zapaljivim materijalom,
- krivi način provjere nepropusnosti,
- neuspjelo gašenje priručnom opremom, izostanak automatskog starta CO2 sustava, nakon prorade problemi s disanjem za operatere,
- korištenje vode za gašenje (procedurom zabranjeno za kabele) ugasilo požar,
- krivo projektirana separacija sigurnosnih sustava
- 18 mjeseci obustave za popravak.

Browns Ferry Fire regulatory influence

Safe shutdown analysis



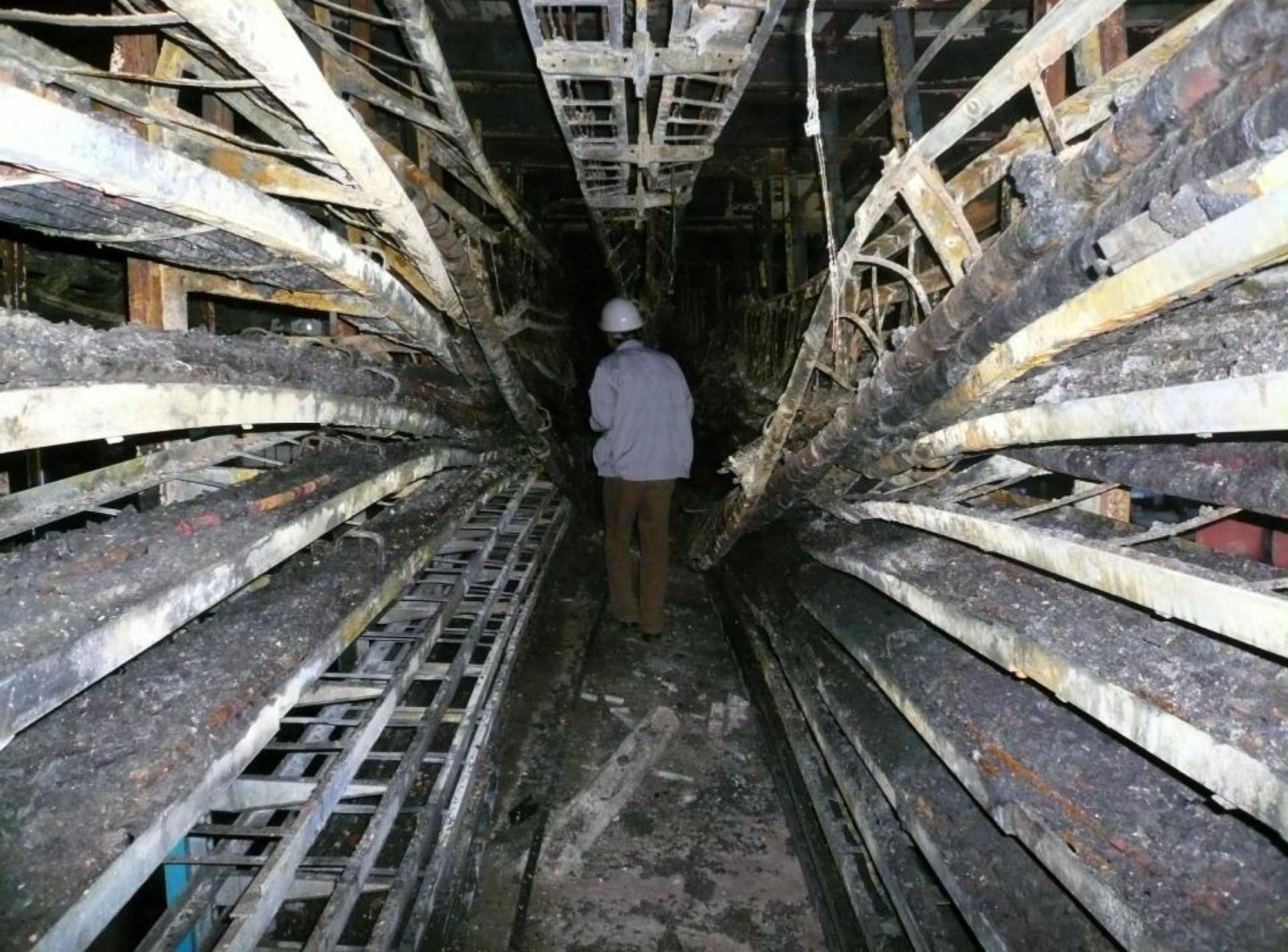
Posljedice vatre u TE













Nesreća u TMI-2

March 28, 1979, 4:00 am local time

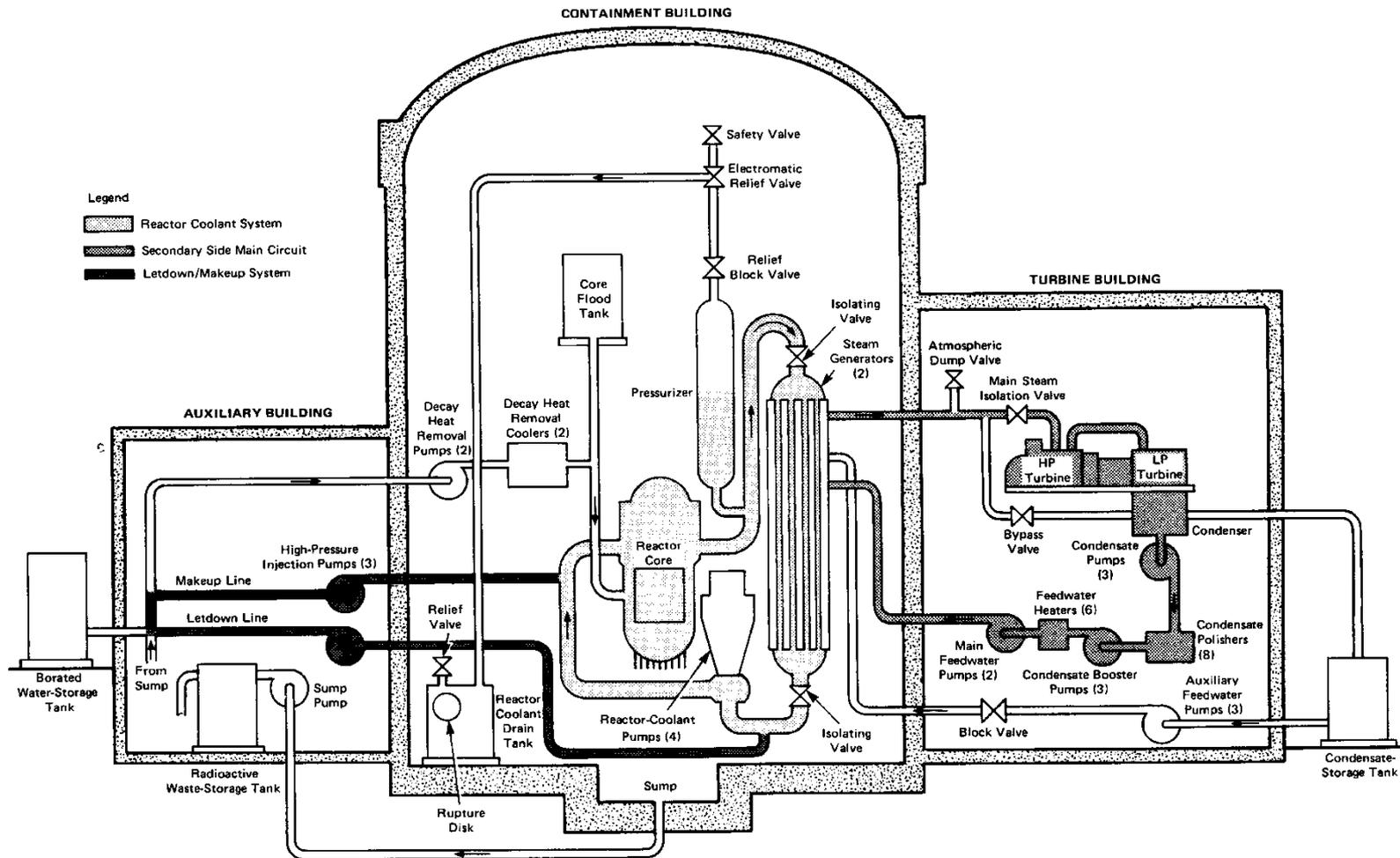


Nesreća u NE Otok tri milje TMI-2

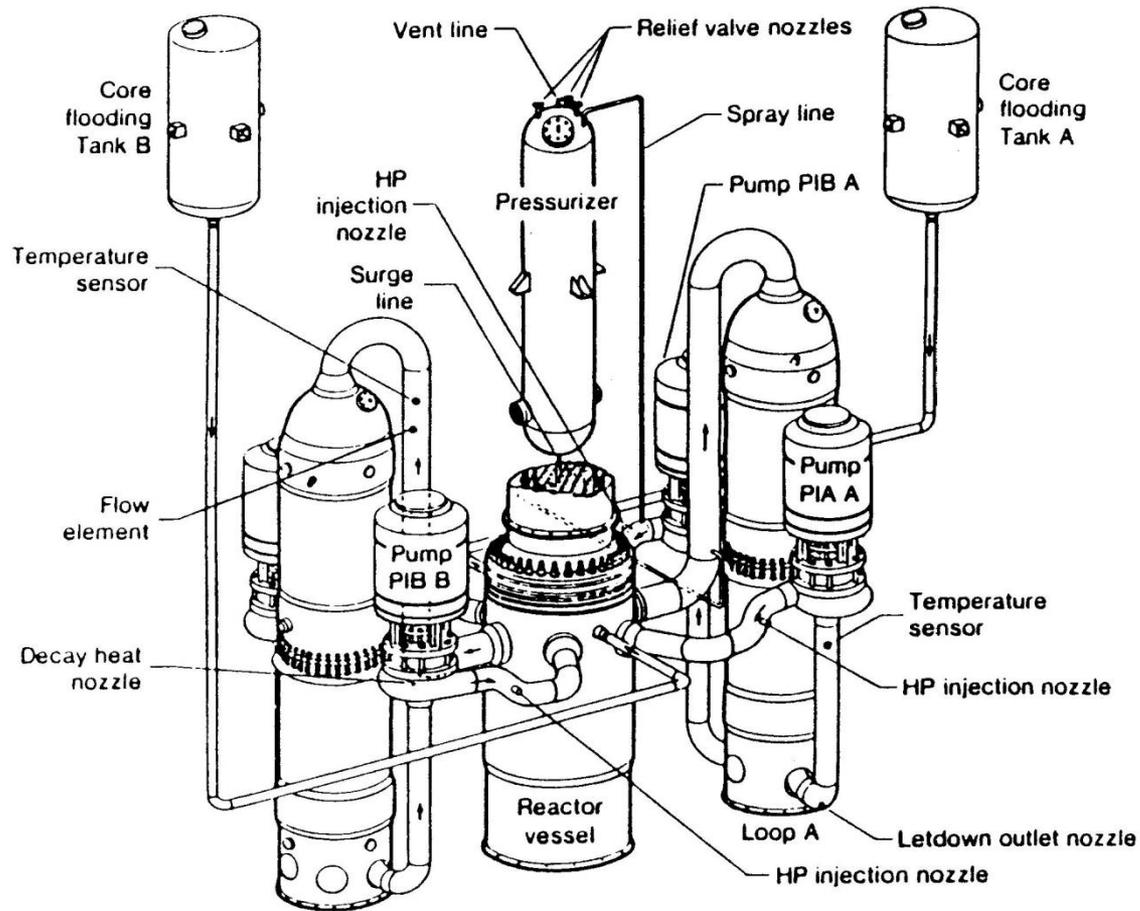
Sekvenca događaja

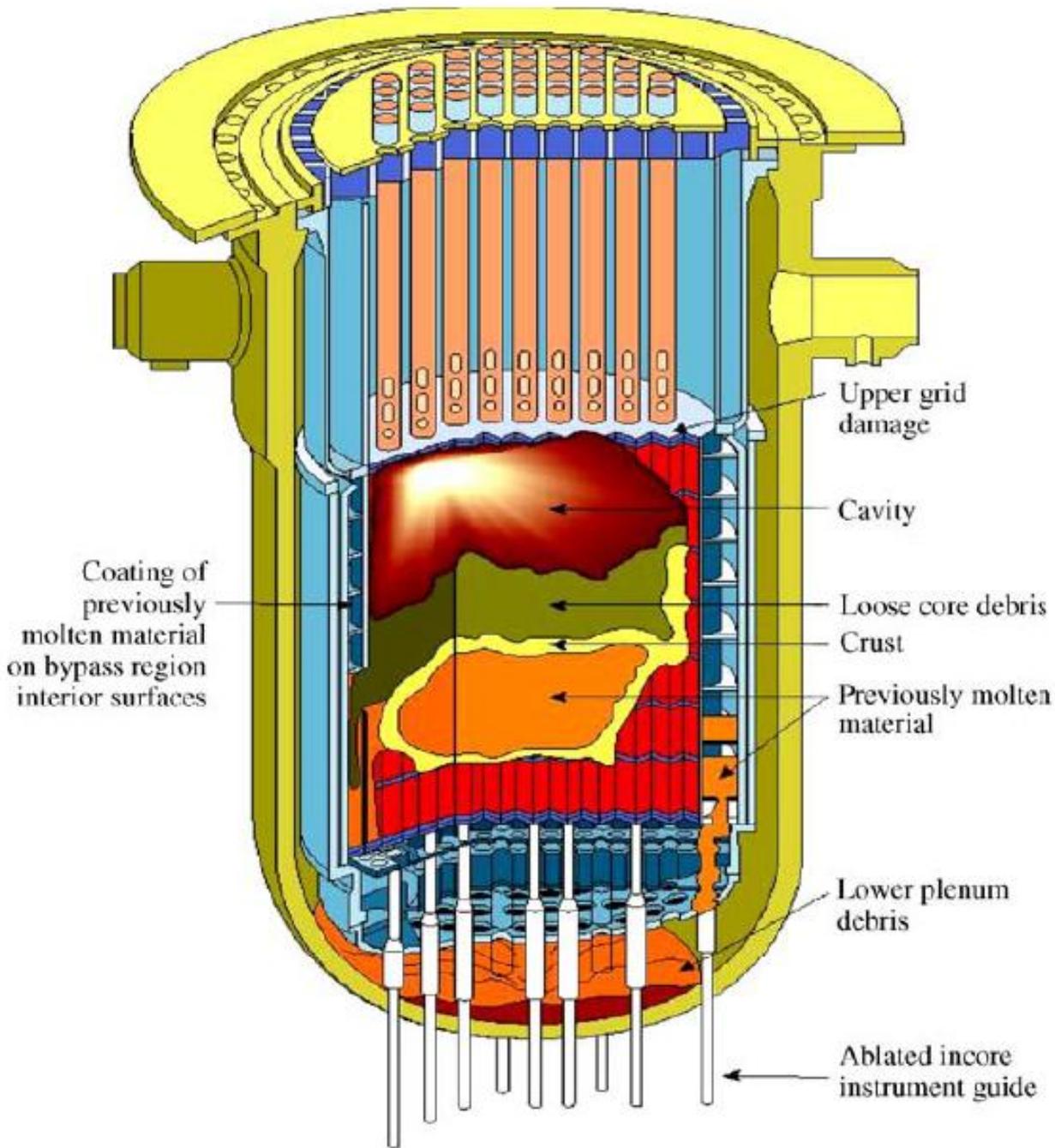
1. Kvar sustava za demineralizaciju pojne vode parogeneratora
2. Ispad pumpi pojne vode
3. Ventil sustava pomoćne pojne vode ostao zatvoren što operateri nisu primijetili
4. Gubitak vode na sekundarnoj strani parogeneratora
5. Pregrijavanje primarnog kruga, porast tlaka, obustava reaktora
6. Otvaranje rasteretnih ventila tlačnika – ostali otvoreni!
7. Primarna voda se gubi, tlak pada, isparavanje vode
8. Operateri zaustavljaju primarne pumpe radi zaštite pumpi
9. Formiranje parnog mjehura u jezgri koji blokira protok vode kroz reaktor i potiskuje vodu u tlačnik
10. Operateri zaustavljaju rad pumpi sustava za zaštitno hlađenje jezgre
11. Pregrijavanje jezgre

Dijelovi NE TMI-2 bitni za razumijevanje nesreće



Reaktorski sistem NE TMI-2





Rezultat – oštećenje jezgre

Izvor topline:
-Ostatna toplina
-egzotermna reakcija
oksidacije

Trajanje akcidenta:
16 sati

Nesreća u NE Otok tri milje TMI-2

- Nesreća na elektrani TMI-2 ukazala je na nedostatke u:
 - izvedbi elektrane
 - procedurama
 - obuci operatera
- Postalo je očigledno da do oštećenja jezgre može doći i kod malog ispuštanja iz primarnog sustava
- Znatno pooštreni sigurnosni zahtjevi ugradnjom novih tehničkih sustava i školovanjem operatera



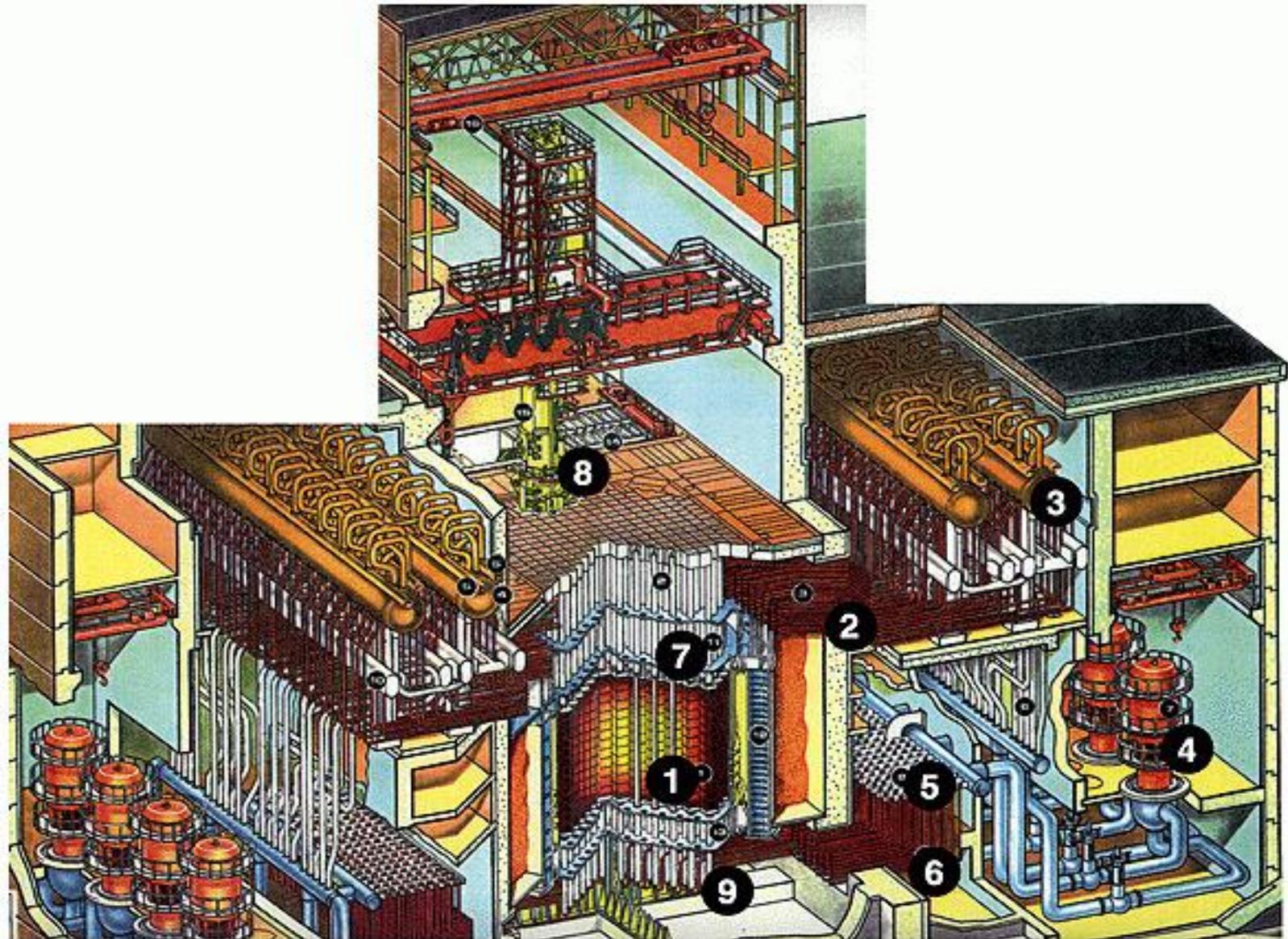
Akcident u Černobilu

- **NE Černobil je imala RBMK-1000 reaktor.**
- **Kao posljedica neoprezno izvedenog eksperimenta na jedinici 4, 26.04.1986., brzi porast snage izazvao je topljenje goriva i razaranje reaktorske zgrade. Slijedile se naknadne eksplozije, pare i vodika te požar grafita.**
- **Radioaktivni materijal je oslobađan u atmosferu tijekom 10 dana.**

NE Černobil



Izgled RBMK reaktora



RBMK-1000 reaktor

Prednost:

- izmjena goriva tijekom pogona – visoka raspoloživost, te mogućnost reguliranja odgora goriva u pojedinim rashladnim kanalima bez potrebe za obustavom pogona

Nedostaci:

- nema zaštitne zgrade
- pozitivan temperaturni koeficijent šupljina (najniža dopuštena termička snaga oko 22 % ukupne snage)
- sporo kretanje regulacijskih šipki (voda u kanalima jezgre ograničava njihovu brzinu kretanja)
- regulacijske šipke u svojem gornjem i donjem dijelu sadrže grafit umjesto apsorpcijskog materijala

Nesreća u NE Černobil

Eksperiment – da li nakon gubitka vanjskog napajanja električnom energijom turbina u zaustavljanju može proizvesti dovoljno električne energije za napajanje sustava za zaštitno hlađenje jezgre prije starta dizel generatora

- plan je bio izvesti eksperiment na 30 % snage (nema tripa reaktora kako bi operateri imali mogućnost ponoviti eksperiment)
- eksperiment se trebao odnositi na ne-nuklearni dio elektrane
- nije bilo koordinacije između osoblja zaduženog za eksperiment i osoblja zaduženog za sigurnost elektrane

Tijek događaja 25.04.1986.

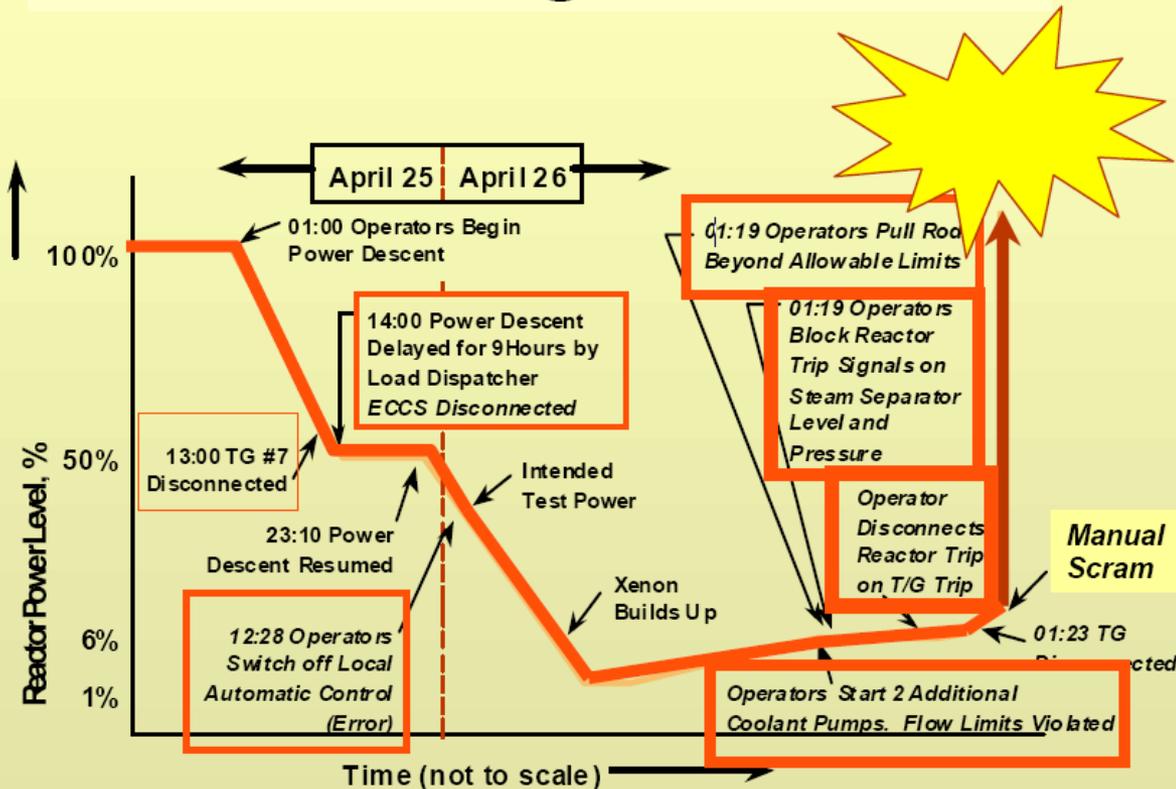
- 01:06 počinje gašenje reaktora, postepeno smanjivanje snage, početak testa
- 03:47 zaustavljeno gašenje na 1600 MW(t), zahtjev kijevskog operatera da elektrana ostane na snazi
- 14:00 izoliran ECCS

Tijek događaja 26.04.1986.

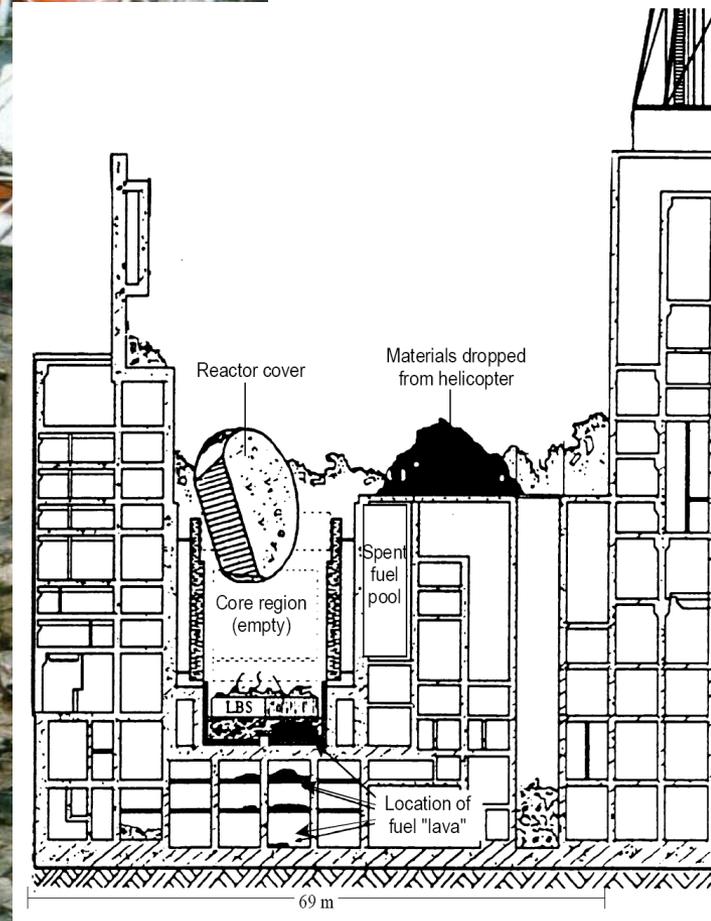
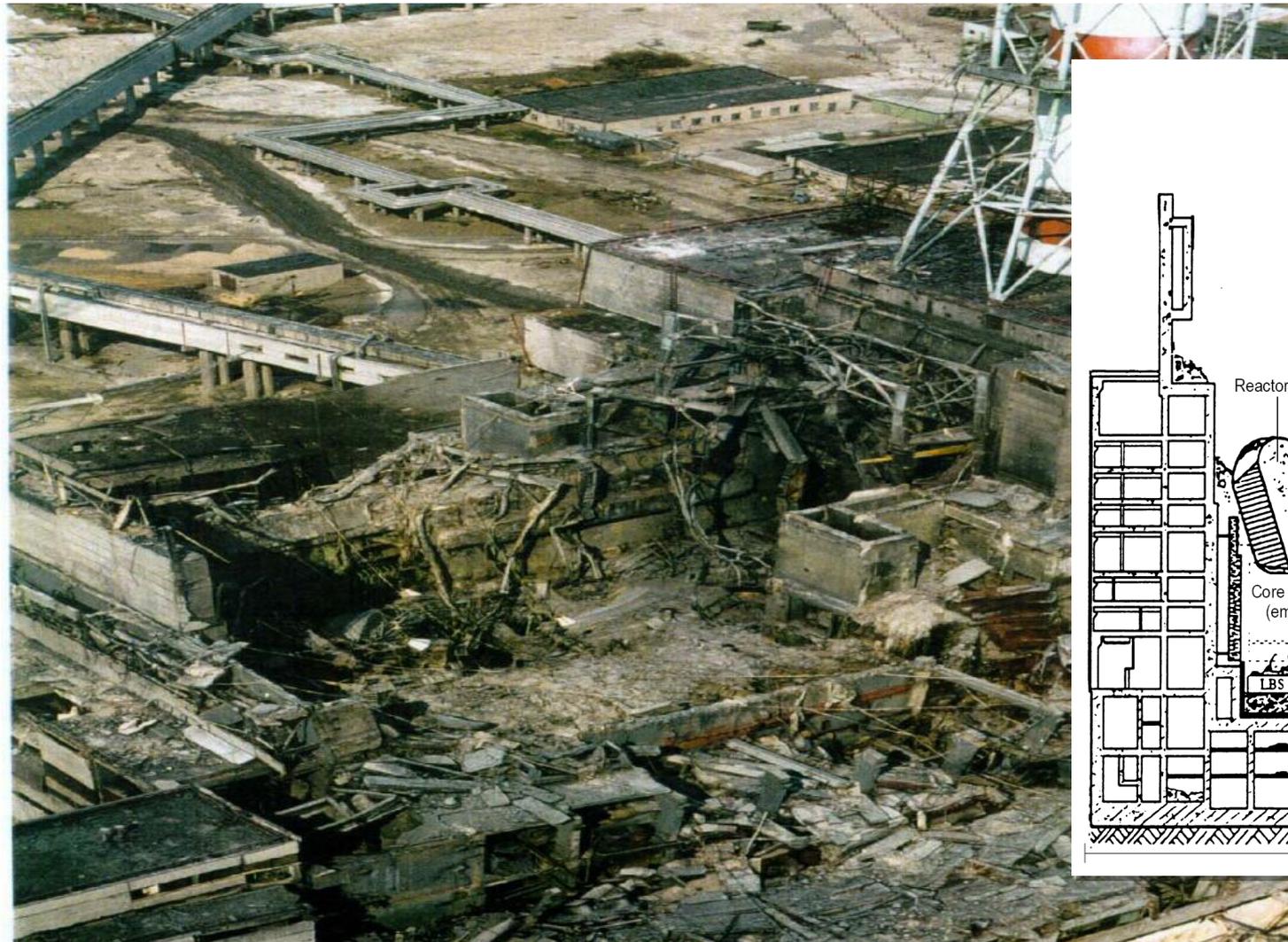
- 01:23:47 snaga reaktora na 30000 MW(t)
 - tlak pare ubrzano raste – prva eksplozija
 - razorena reaktorska zgrada – jezgra izložena atmosferi
 - taljenje gorivih elemenata
 - reakcija goriva i obloge – vodik – druga eksplozija
 - vrući grafit počinje gorjeti u dodiru s kisikom iz atmosfere

Tijek događaja

Events Leading to Accident



Posljedice razaranja



Nesreća u NE Černobil - uzroci

- primarni uzrok (ljudska pogreška) - serija narušavanja instrukcija i operativnih procedura
- sekundarni uzrok (pozitivni koeficijent reaktivnosti i ostali nedostaci izvedbe elektrane)

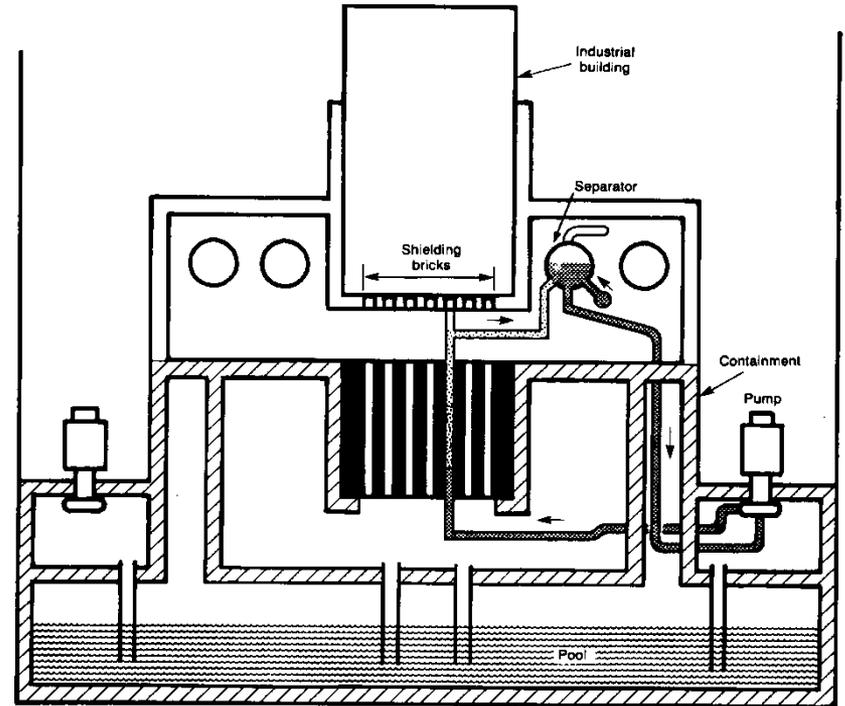
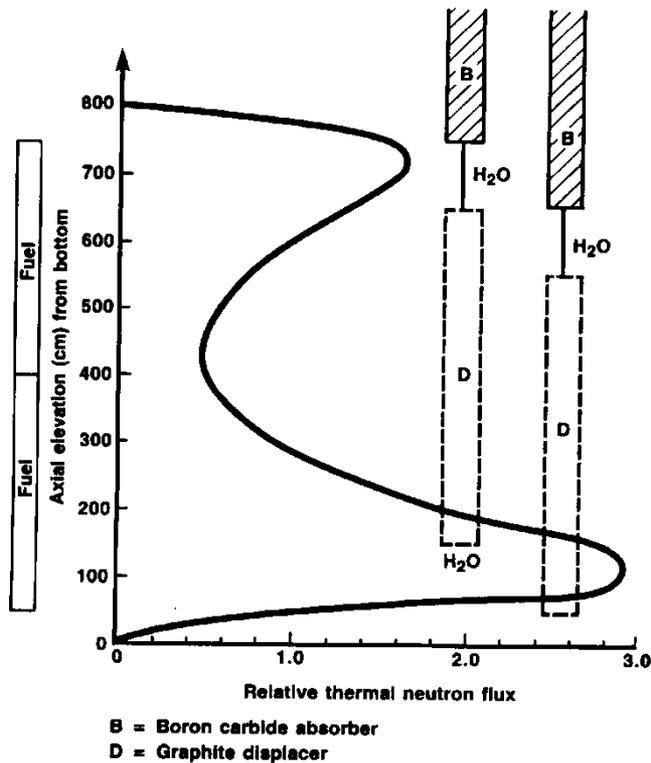


Figure 5 Axial flux distribution preceding accident.

Nesreća u NE Černobilj - posljedice

- 31 žrtva neposredno nakon nesreće
- 134 su liječena od posljedica akutnog rđijacijskog sindroma
- Prema IAEA dokumentu INSAG-1 može se računati sa 170 dodatnih smrtnih slučajeva od raka
- procijenjeno povećanje rizika od smrtnosti zbog raka stanovništva zemalja zahvaćenim radioaktivnim oblakom varira od 0,03 % do 0,15 % u odnosu na neozračenu populaciju
- nesreća je imala ogroman negativan utjecaj na razvoj nuklearne energetike, iako RBMK nije relevantan za današnju nuklearnu energetiku

Chernobyl Accident Consequences

Actual Health Consequences

<u>Population</u>	<u>Number</u>
• Early fatalities (non-radiation)	2 (immediate)
• Early fatalities (radiation)	28 (within 4 m)
• Late adult fatalities (radiation)	19 (as of 9/05)
• Late child fatalities (radiation)	9* (as of 9/05)
• Clinical psychological effects	~ 5,000,000

*All thyroid cancer deaths in population of 4000 identified and treated cases.

Utjecaj na zdravlje - NGO

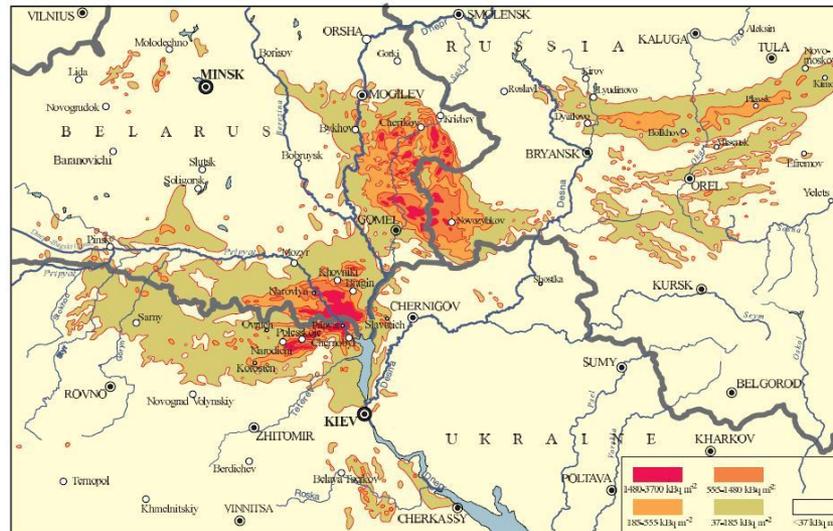
- 31 neposredna žrtva
- Približno 2500 dodatnih smrti vezano za akcident
- Značajan porast raka štitne žljezde
- Učestalost raka štitne žljezde u populaciji do 15 godina povećana od 4 do 6 u milion stanovnika (1981-1985) na 45 u milion stanovnika (na nivou cijele Ukrajine) u razdoblju 1986 do 1997
- 64% slučajeva zabilježeno u najzagađenijim područjima.

Nezdravstveni utjecaj na lokalnu zajednicu

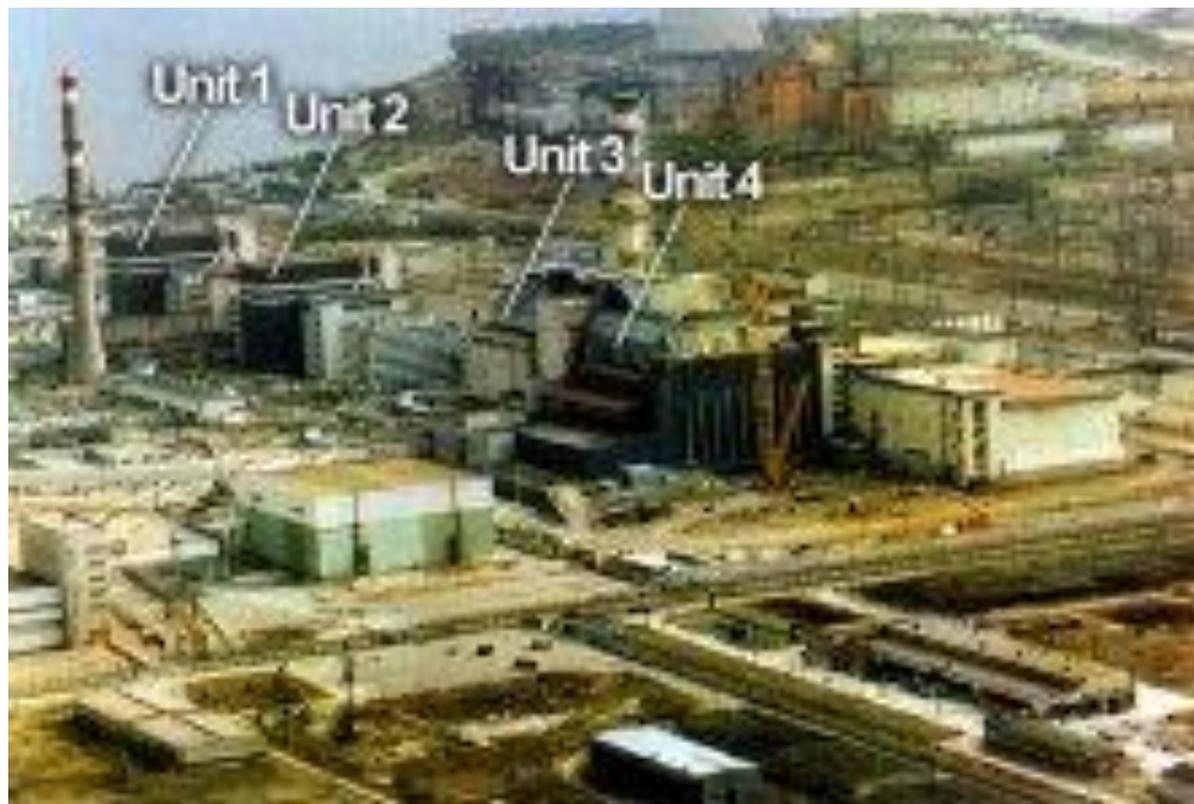
- 116,000 ljudi evakuirano od 1990 do 1995 i 210,000 relocirano.
- Promjene u osnovnoj infrastrukturi
- Manjak električne energije
- Poljoprivredne aktivnosti znatno smanjene s direktnim utjecajem na prihod stanovništva.

Utjecaj na okoliš

- Radioaktivna kontaminacija u dobrom dijelu Europe, u konačnici gotovo cojela sjeverna hemisfera.
- U lokalnom ekosustavu (10 km radius) promjene na stablima, smrt malih sisavaca.
- Okoliš se oporavlja ali na duge staze mogući su genetski efekti.



Cs-137

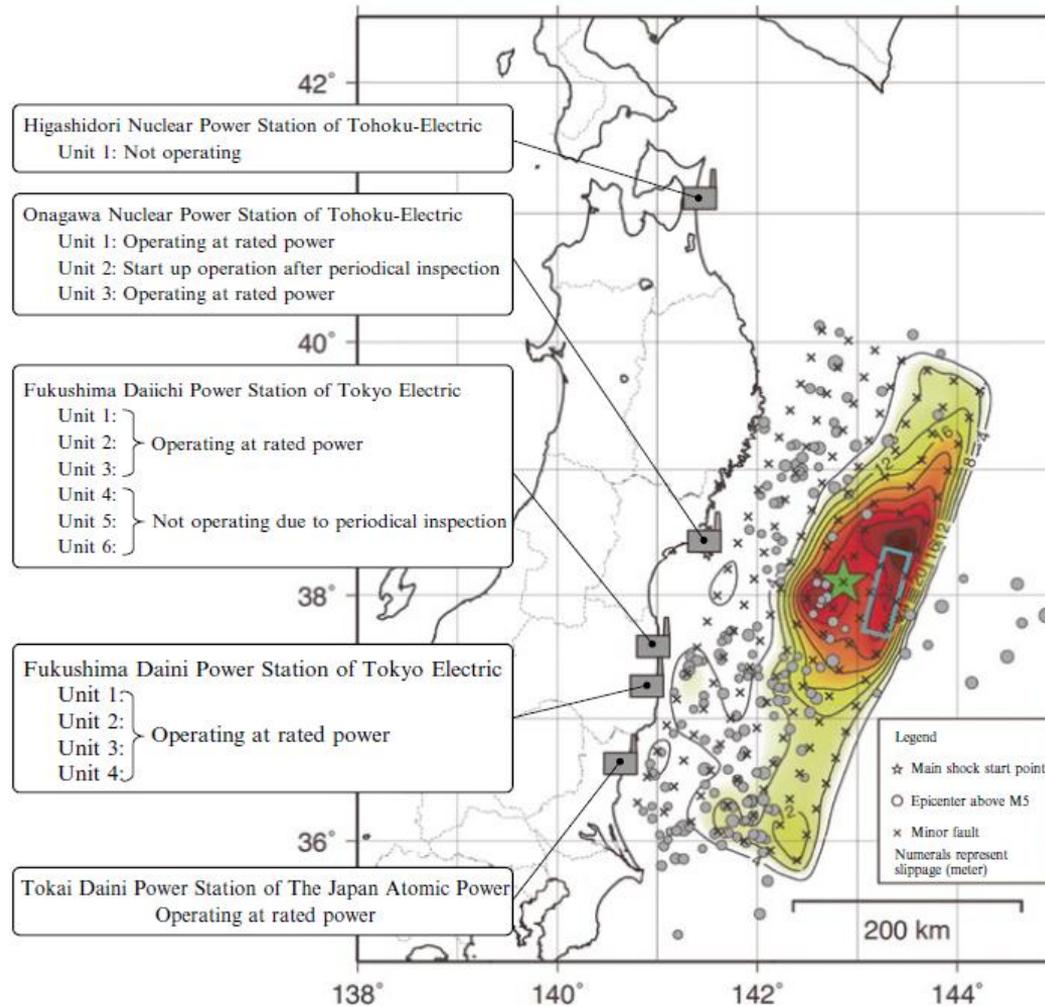




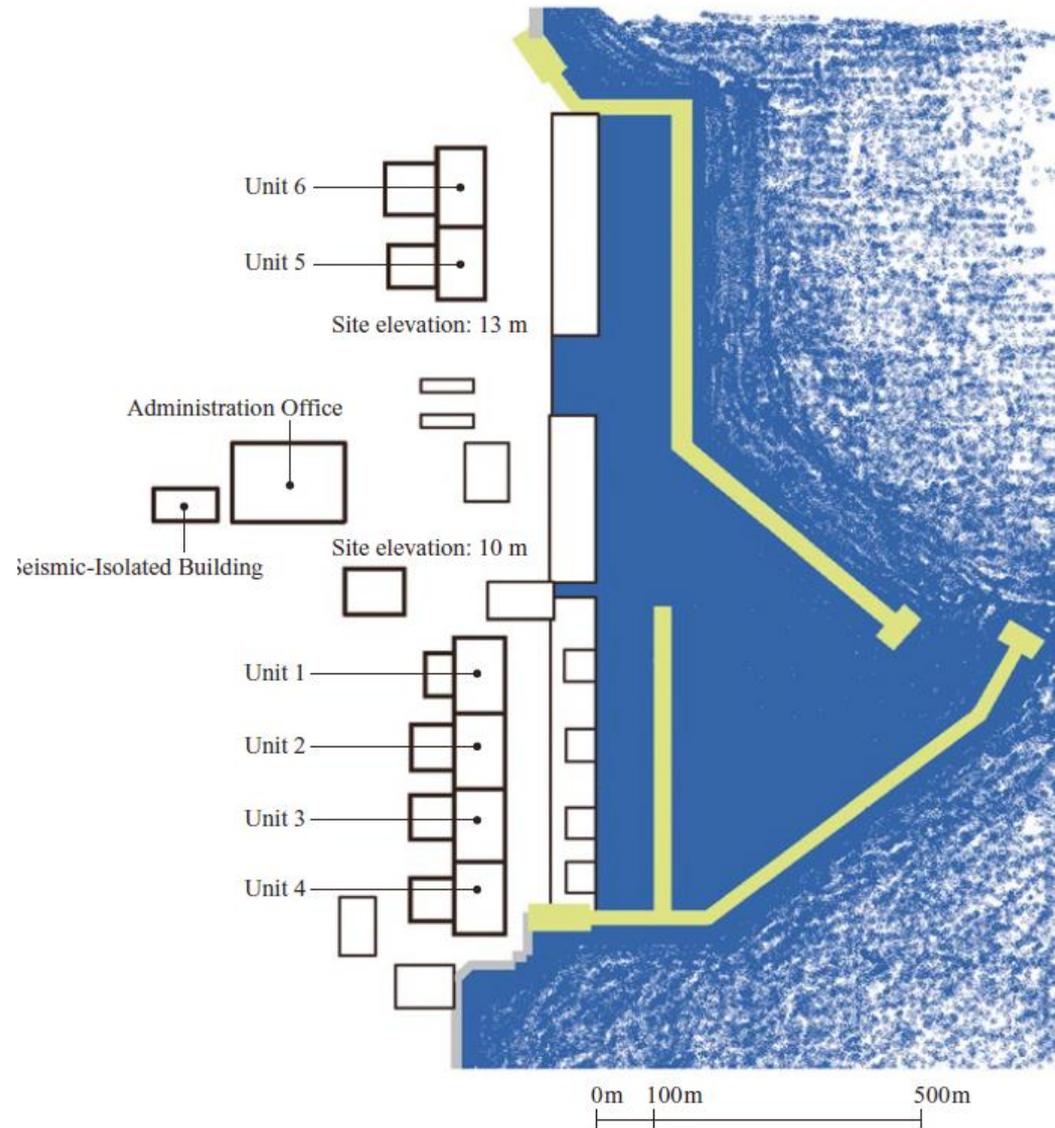
Černobilski eko-paradoks



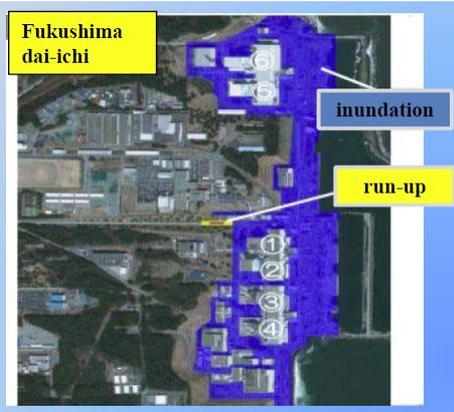
Fukushima



Fukushima Daiichi NPP Layout



Fukushima Daiichi

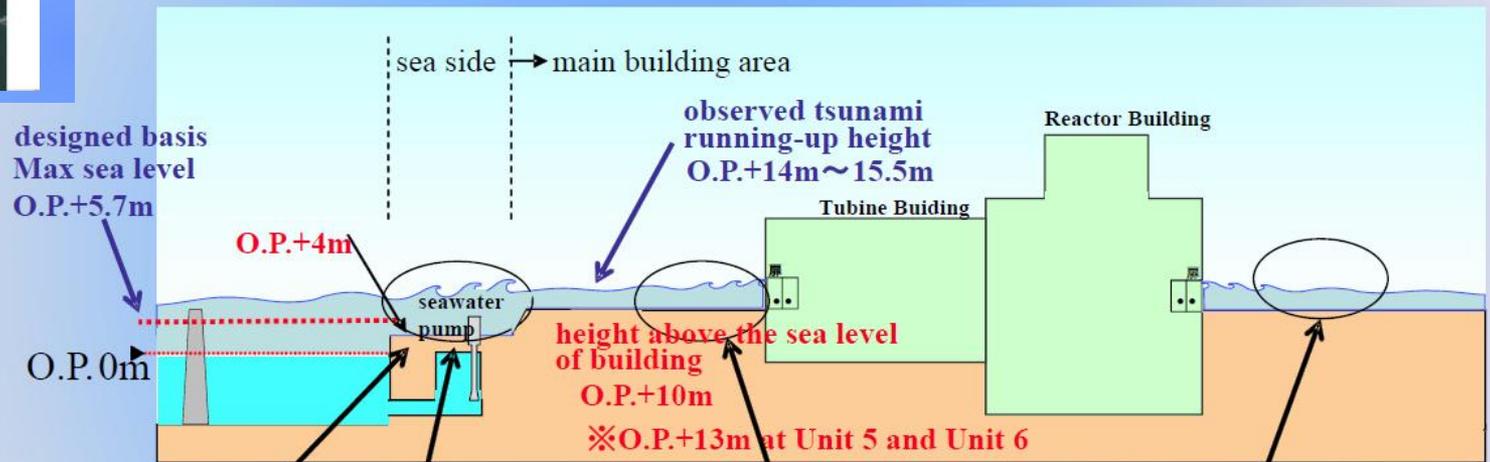


designed basis tsunami height
= +5.7m

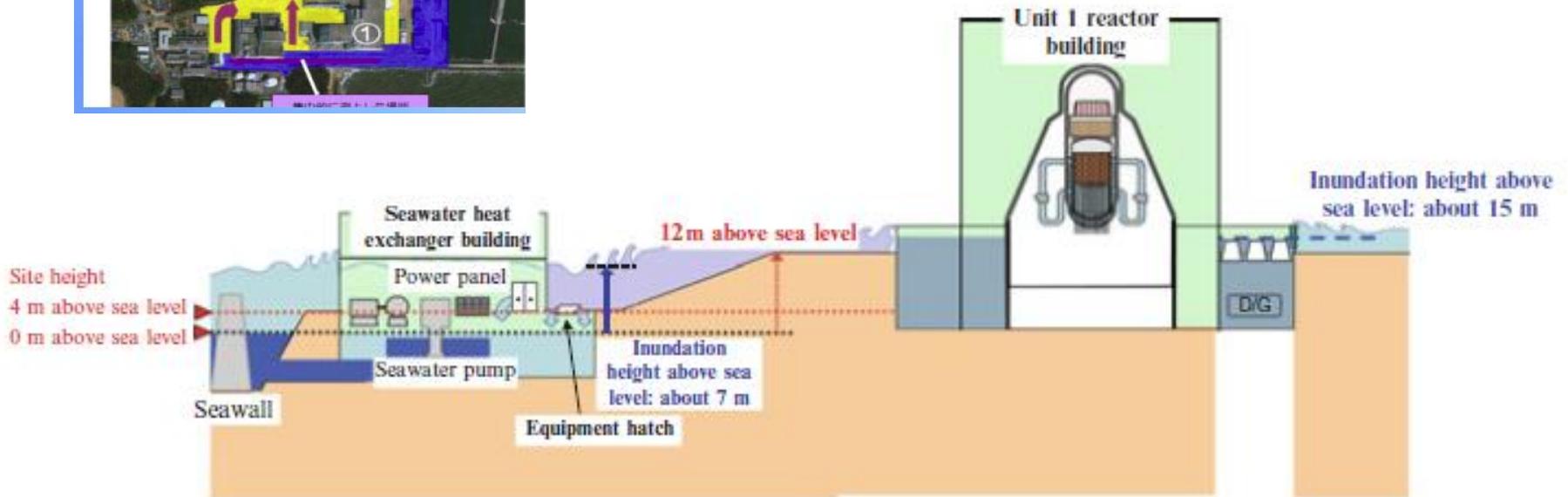


observed tsunami running-up height
= +14m~15.5m

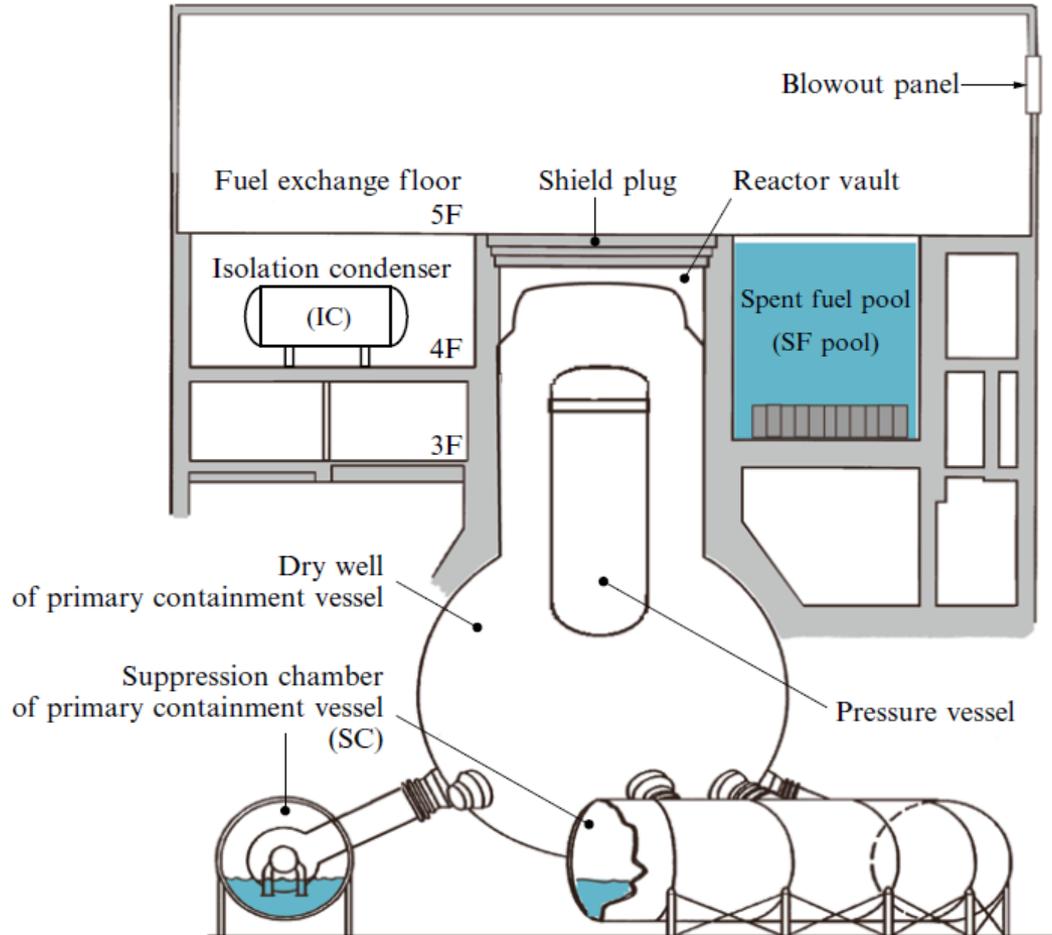
< Height above the sea level of building at Unit1~Unit4 and tsunami >



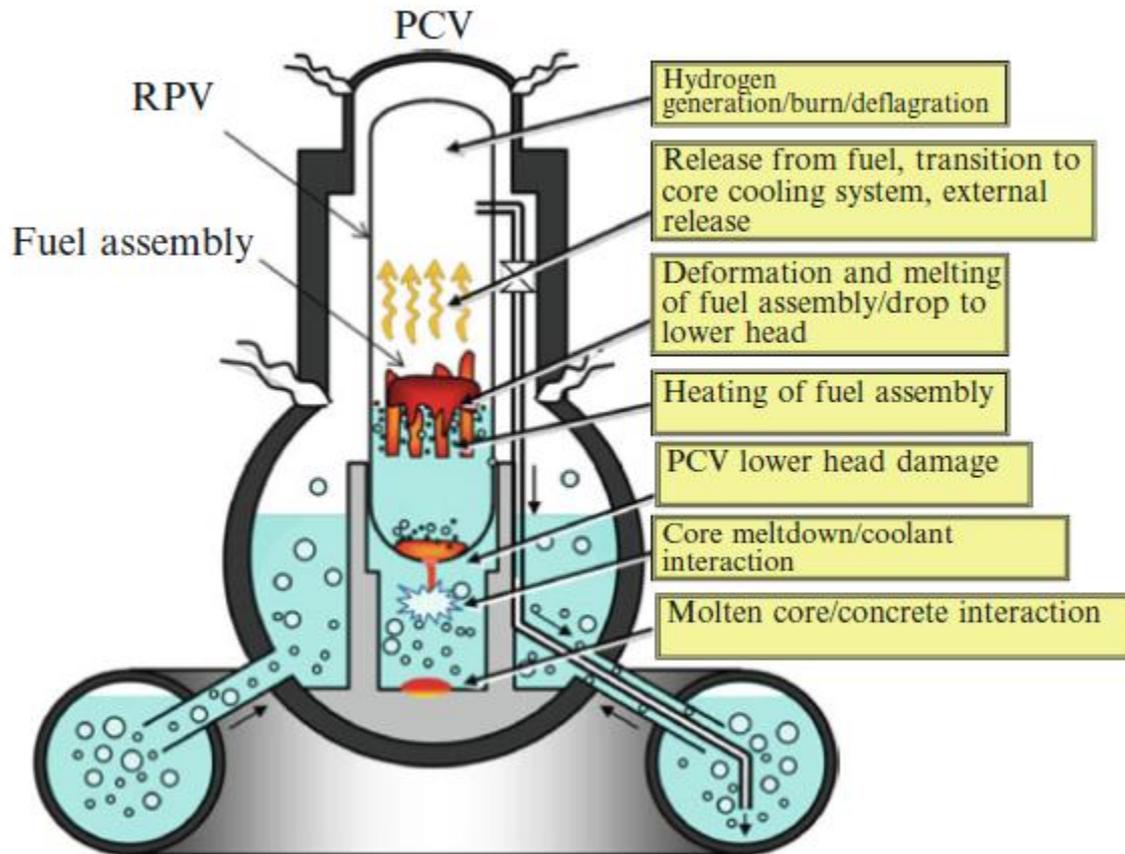
Fukushima Dai-ichi



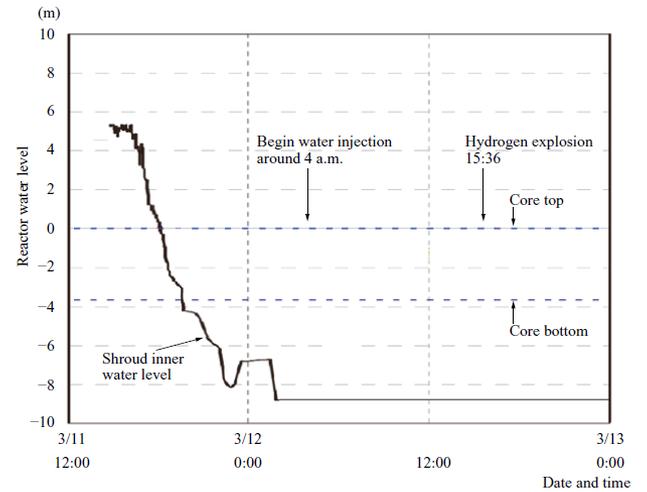
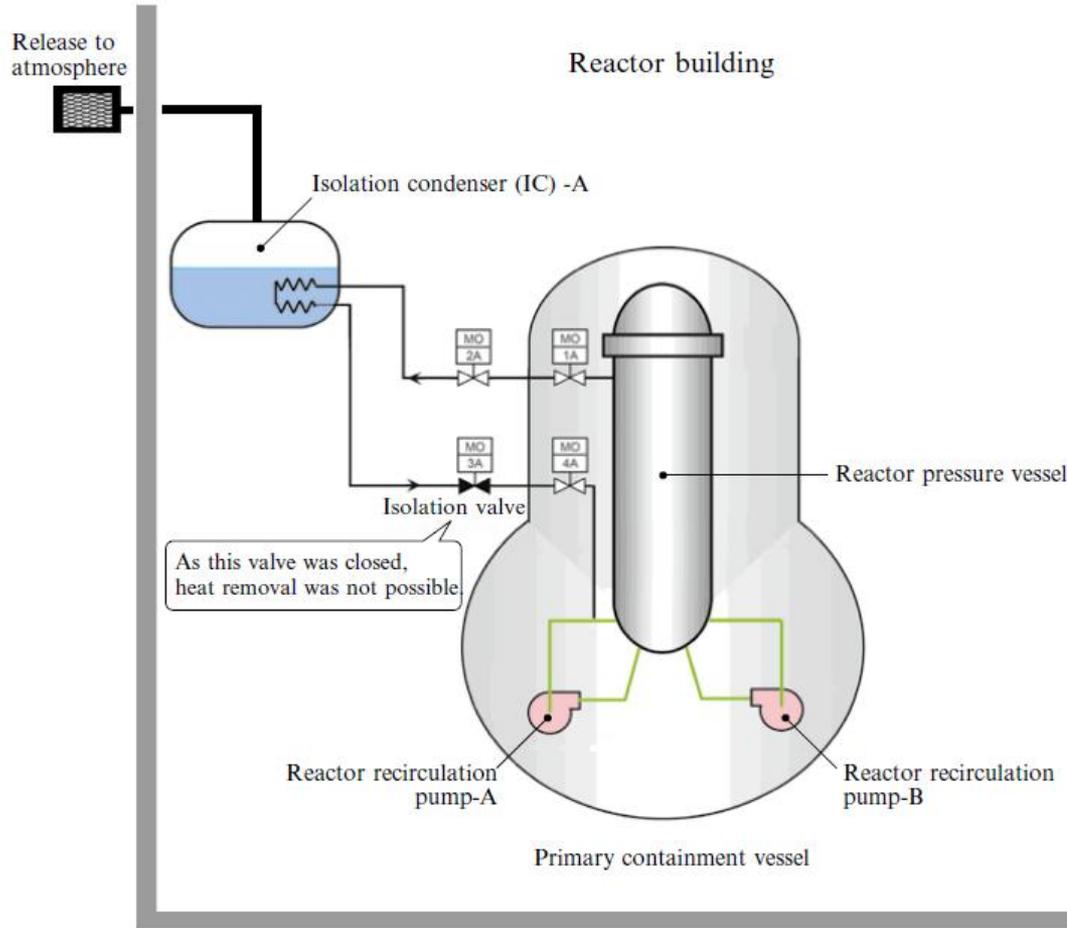
Mark-I BWR



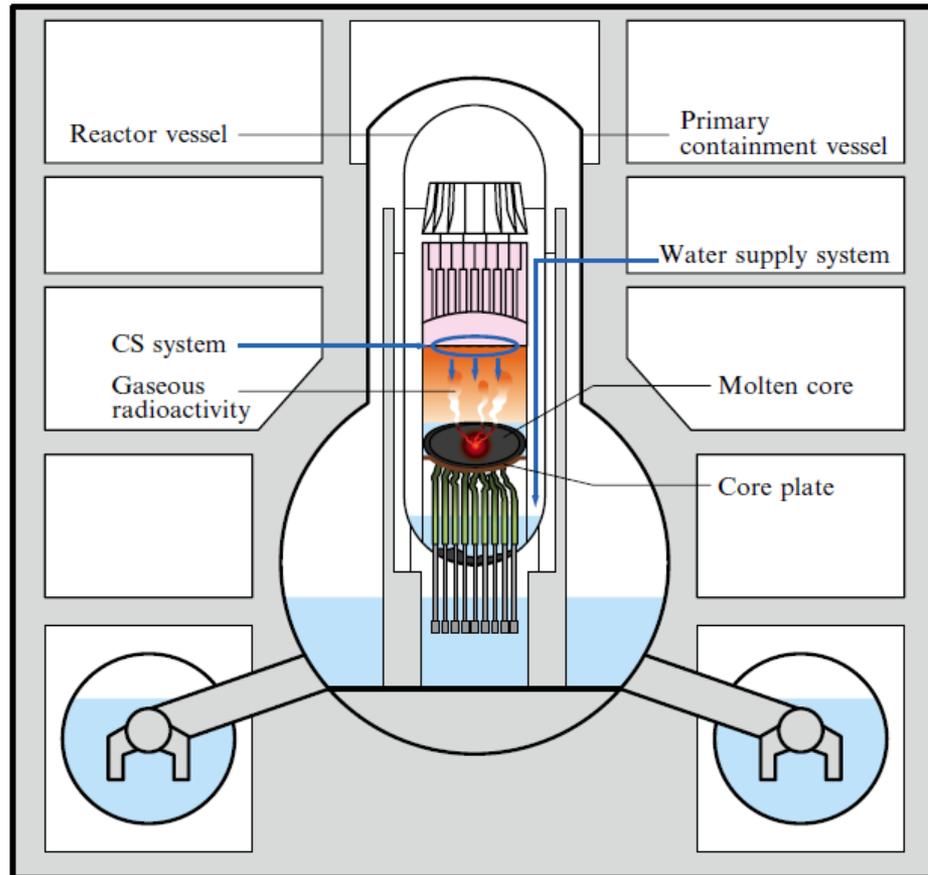
Relevant phenomena during severe accident



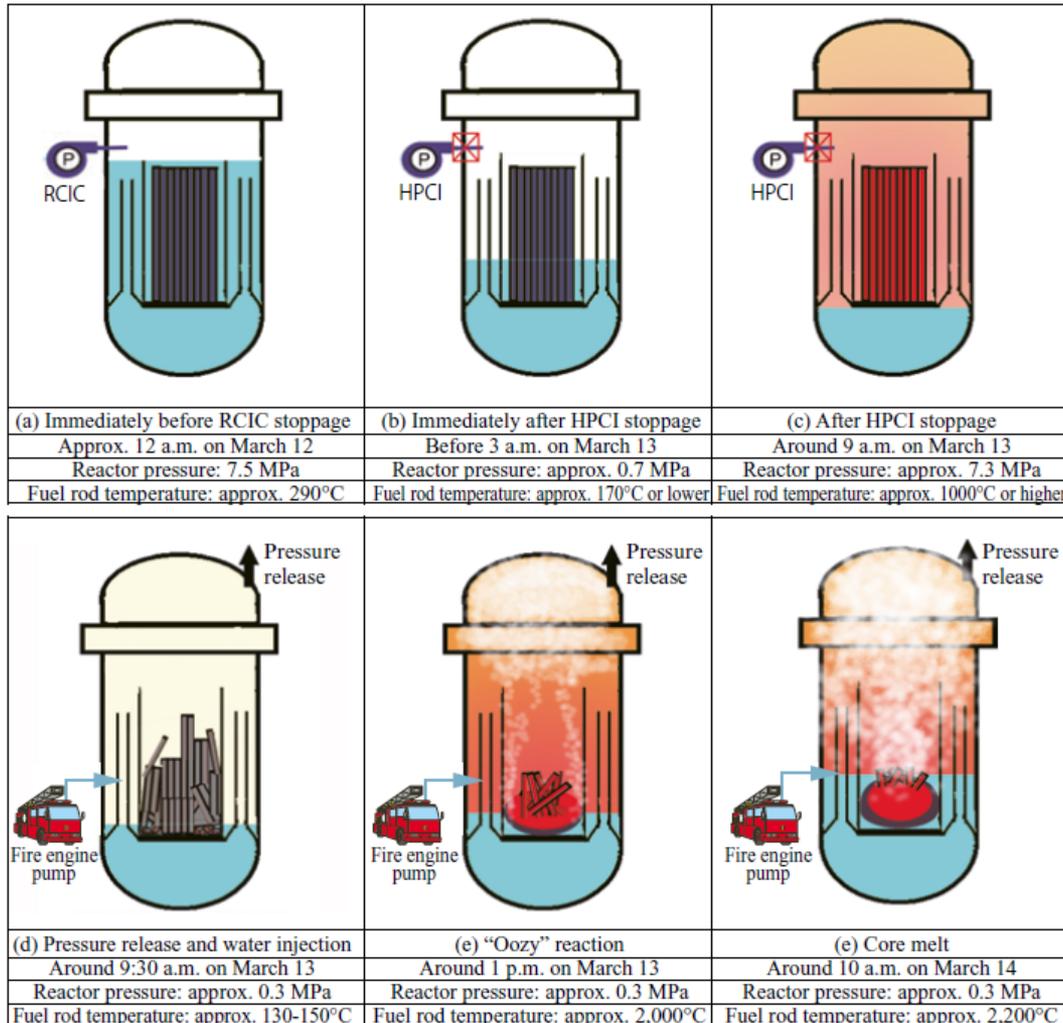
Unit 1



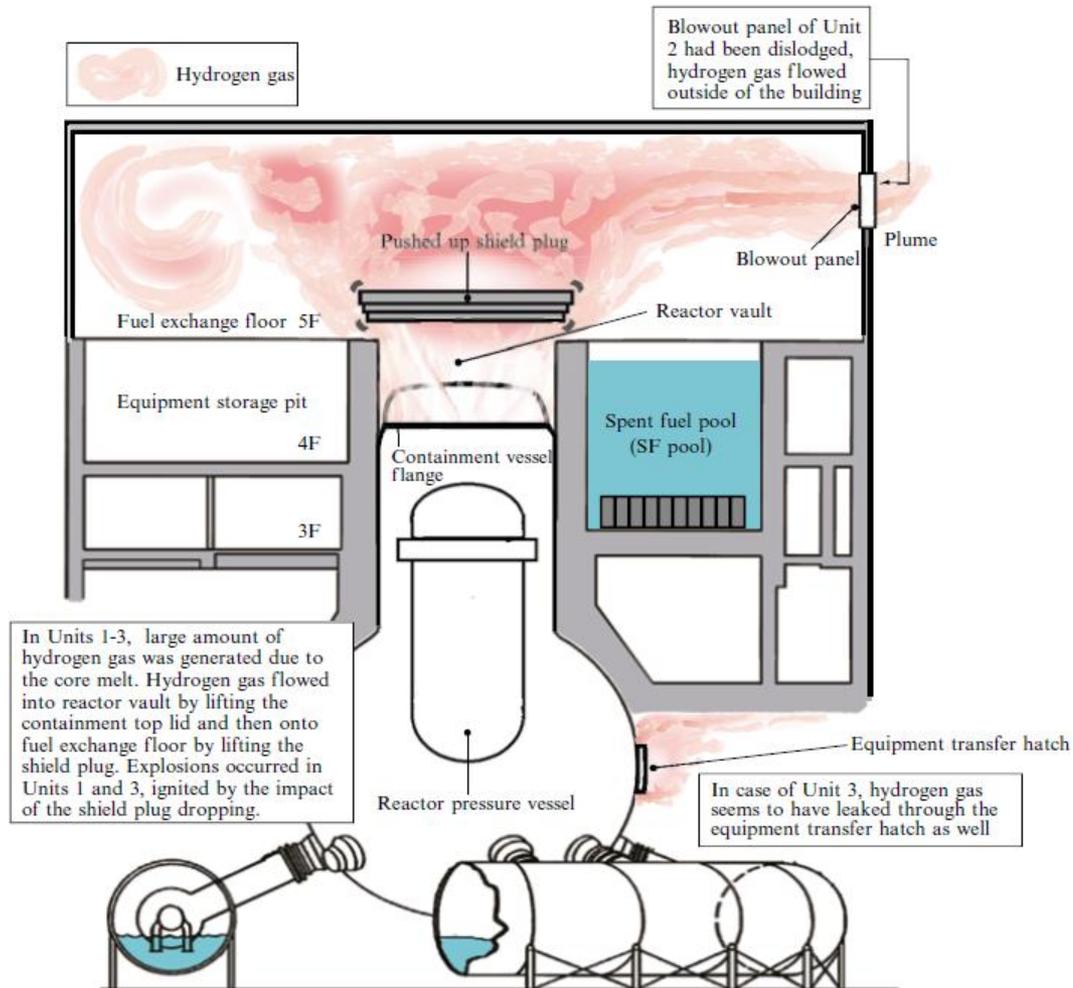
Unit 2



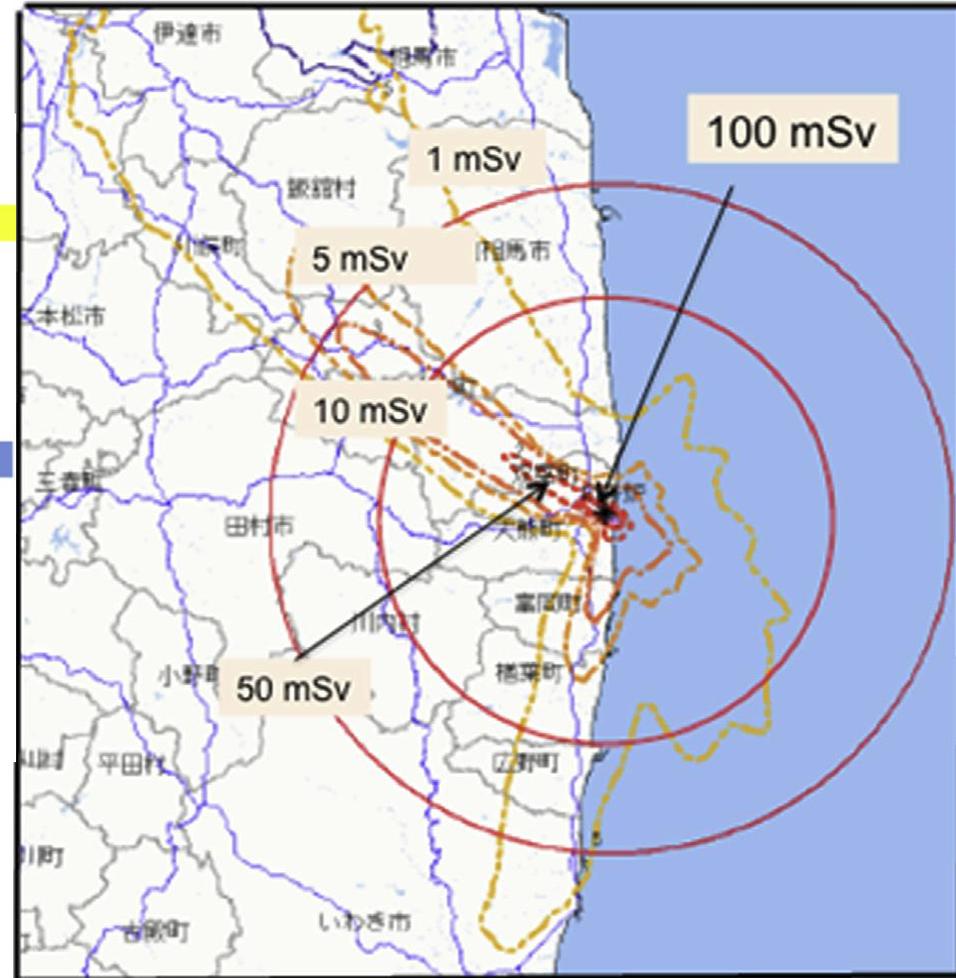
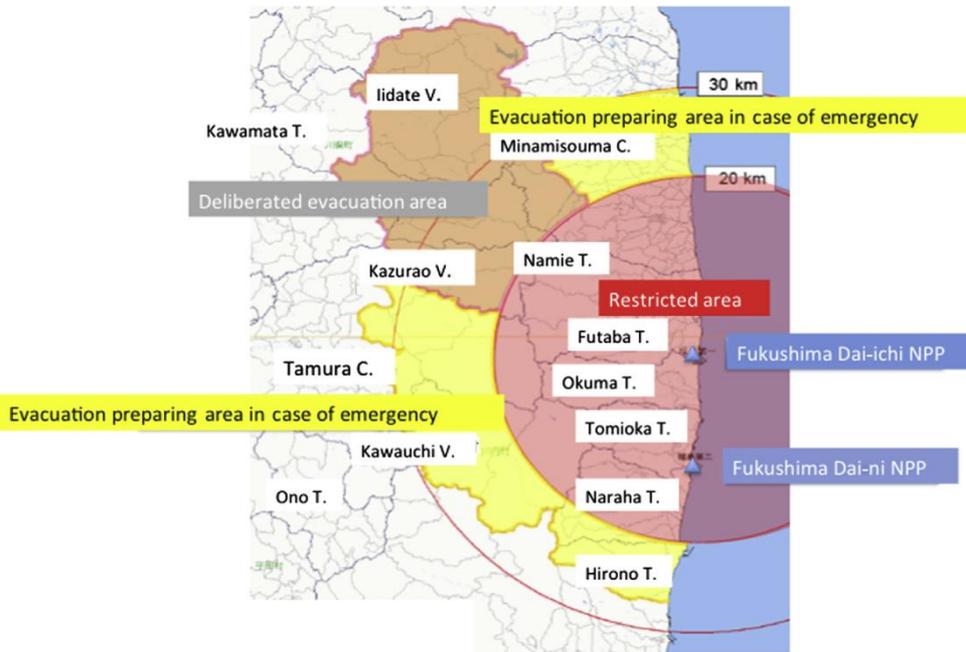
Unit 3



H₂ production, leakage, explosion

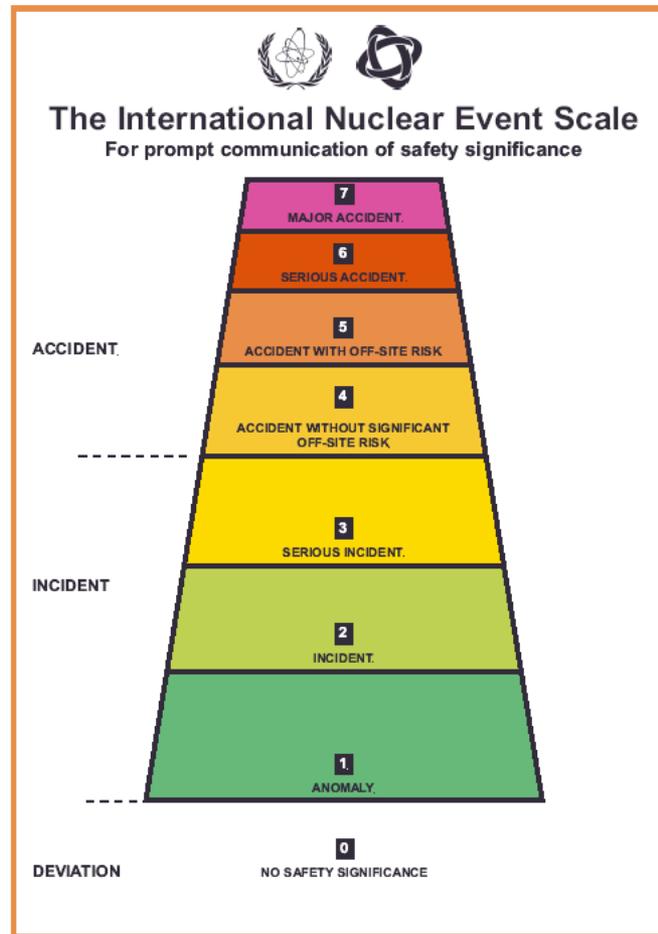


Evacuation zone/effective dose



Međunarodna skala nuklearnih događaja

Promptna informacija o značaju događaja za sigurnost



INES

Basic Structure of the Scale

*(Criteria given in matrix are broad indicators only)
Detailed definitions are provided in the INES User's Manual*

	CRITERIA OR SAFETY ATTRIBUTES		
	OFF-SITE IMPACT	ON-SITE IMPACT	DEFENCE IN DEPTH DEGRADATION
7 MAJOR ACCIDENT	MAJOR RELEASE: WIDESPREAD HEALTH AND ENVIRONMENTAL EFFECTS		
6 SERIOUS ACCIDENT	SIGNIFICANT RELEASE: LIKELY TO REQUIRE FULL IMPLEMENTATION OF PLANNED COUNTERMEASURES		
5 ACCIDENT WITH OFF-SITE RISK	LIMITED RELEASE: LIKELY TO REQUIRE PARTIAL IMPLEMENTATION OF PLANNED COUNTERMEASURES	SEVERE DAMAGE TO REACTOR CORE/RADIOLOGICAL BARRIERS	
4 ACCIDENT WITHOUT SIGNIFICANT OFF-SITE RISK	MINOR RELEASE: PUBLIC EXPOSURE OF THE ORDER OF PRESCRIBED LIMITS	SIGNIFICANT DAMAGE TO REACTOR CORE/RADIOLOGICAL BARRIERS/FATAL EXPOSURE OF A WORKER	

INES

4 ACCIDENT WITHOUT SIGNIFICANT OFF-SITE RISK	MINOR RELEASE: PUBLIC EXPOSURE OF THE ORDER OF PRESCRIBED LIMITS	SIGNIFICANT DAMAGE TO REACTOR CORE/RADIOLOGICAL BARRIERS/FATAL EXPOSURE OF A WORKER	
3 SERIOUS INCIDENT	VERY SMALL RELEASE: PUBLIC EXPOSURE AT A FRACTION OF PRESCRIBED LIMITS	SEVERE SPREAD OF CONTAMINATION/ACUTE HEALTH EFFECTS TO A WORKER	NEAR ACCIDENT NO SAFETY LAYERS REMAINING
2 INCIDENT		SIGNIFICANT SPREAD OF CONTAMINATION/ OVEREXPOSURE OF A WORKER	INCIDENTS WITH SIGNIFICANT FAILURES IN SAFETY PROVISIONS
1 ANOMALY			ANOMALY BEYOND THE AUTHORIZED OPERATING REGIME
0 DEVIATION	NO	SAFETY	SIGNIFICANCE
OUT OF SCALE EVENT	NO SAFETY RELEVANCE		

