High Power Water Beam Dump for a LC

(e.g. TESLA 800)

- Latest Status and News -

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TESLA Collaboration Meeting, APDG-WG-II, Tue. 16. Sep. 2003

A. Introduction

B. Thermal Aspects

C. Other Processes

D. Radiation Handling

E. Conclusion

A: Introduction

· **Why Water instead of Solid Dump? ® driven by heat extraction issue**

· **Schematic Layout of Water Dump System ® see A1**

· **Problems to be adressed:**

Thermal Aspects
- heat extraction external / internal

Other Processes
- radiolysis
- pressure waves

Radiation Handling
- activation
- dismantling & removal of activated matter (water) @ final shut down

Þ Feasibility Study by 2 Companies

1.) Framatome (Erlangen): former Siemens / KWU, construction of nuclear power plants

2.) Fichtner (Stuttgart): engineering / consulting, worldwide operating, power plants

· **Studies based on following Assumptions:**

- **beam: 400GeV, 6.84×10^{13} e-, 4Hz, 4.4MJ per train resp. 17.5MW in average**
  s_x = s_y=0.55mm and fast (within train) circular sweep with R_{fast}=8cm
- **water dump: cylindrical H_2O volume, L=10m, Ø=1.5m, 10bar=10^6Pa Þ T_{boil}=180°C**
- **not considered: window and beam pipe, beamstrahlungsdump and g-dump of e+ target**

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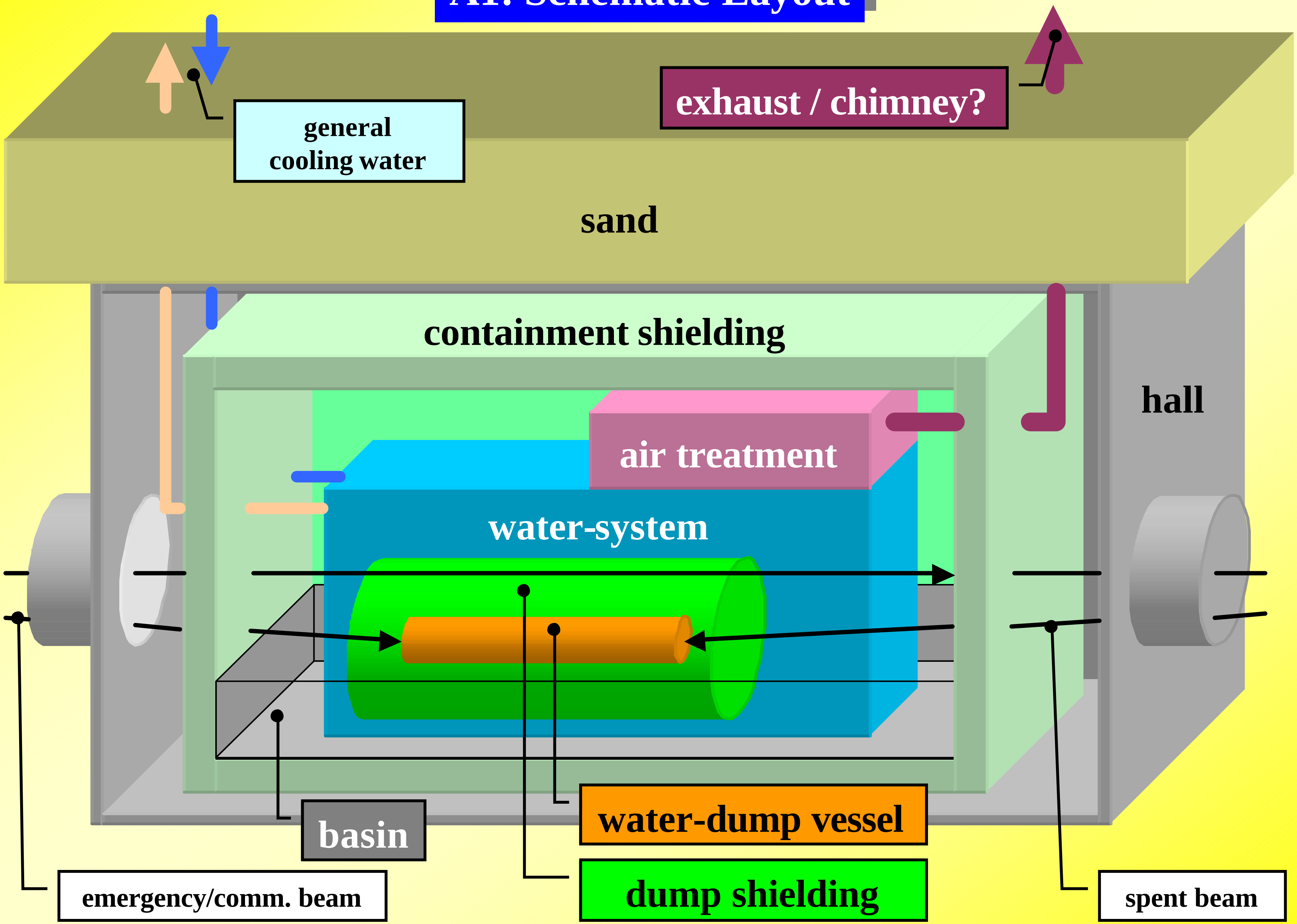
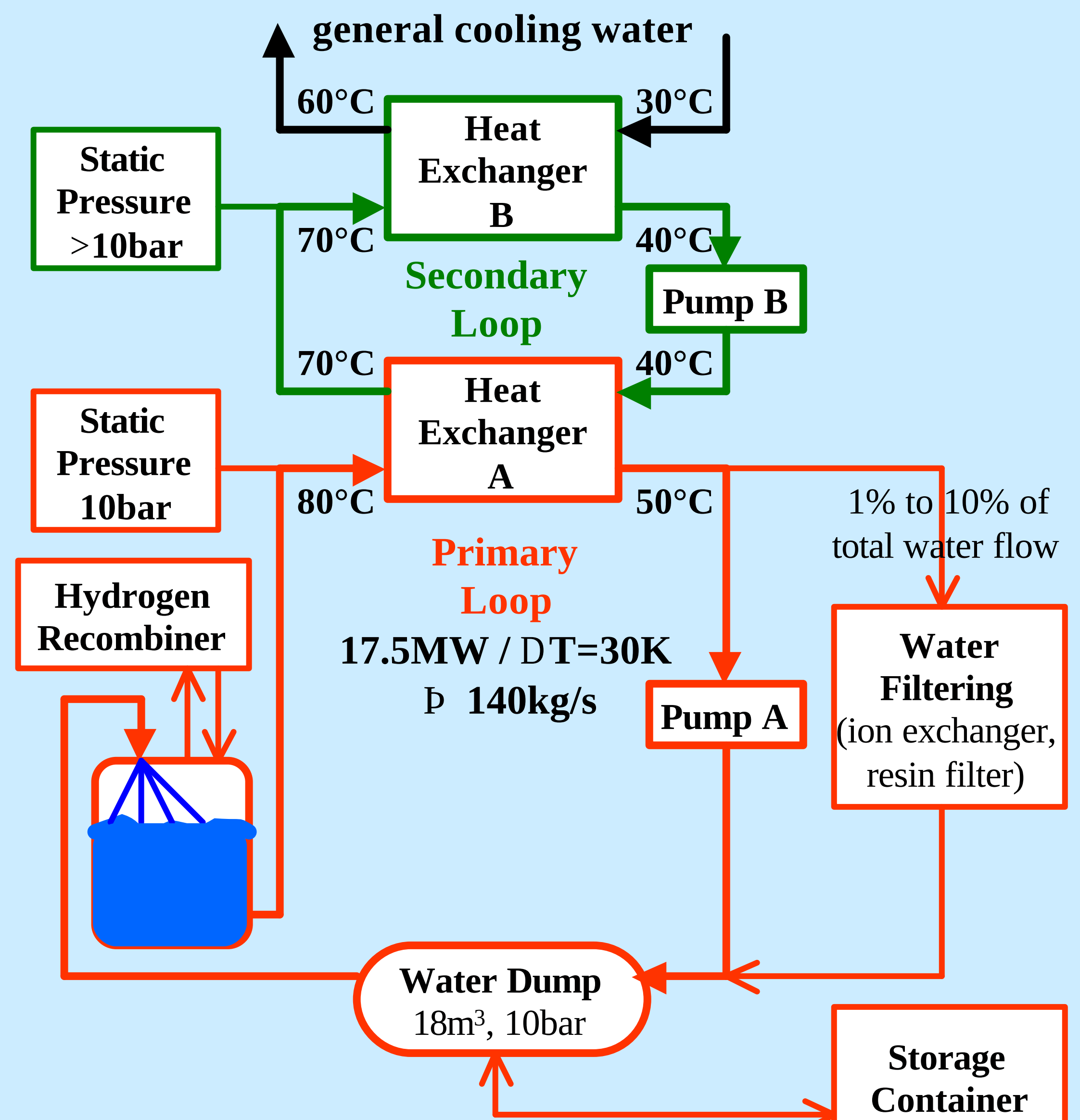
A1: Schematic Layout



B1.1: External Water System – general scheme

- two loop system with $p_B > p_A$
- main piping DN 350mm
- both companies mainly agree in layout of water system



Scheme of Water System

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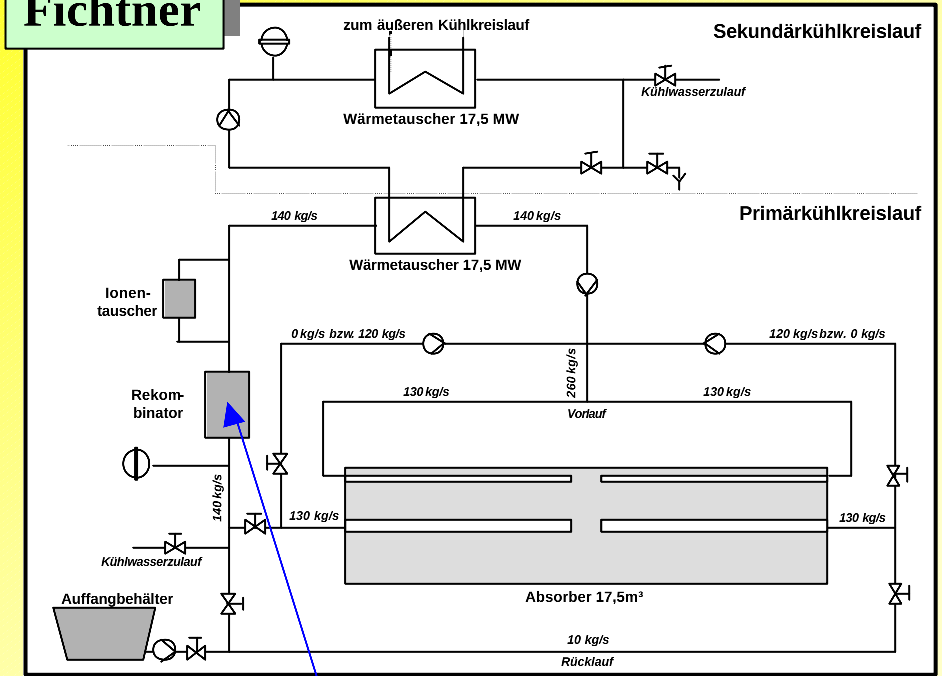
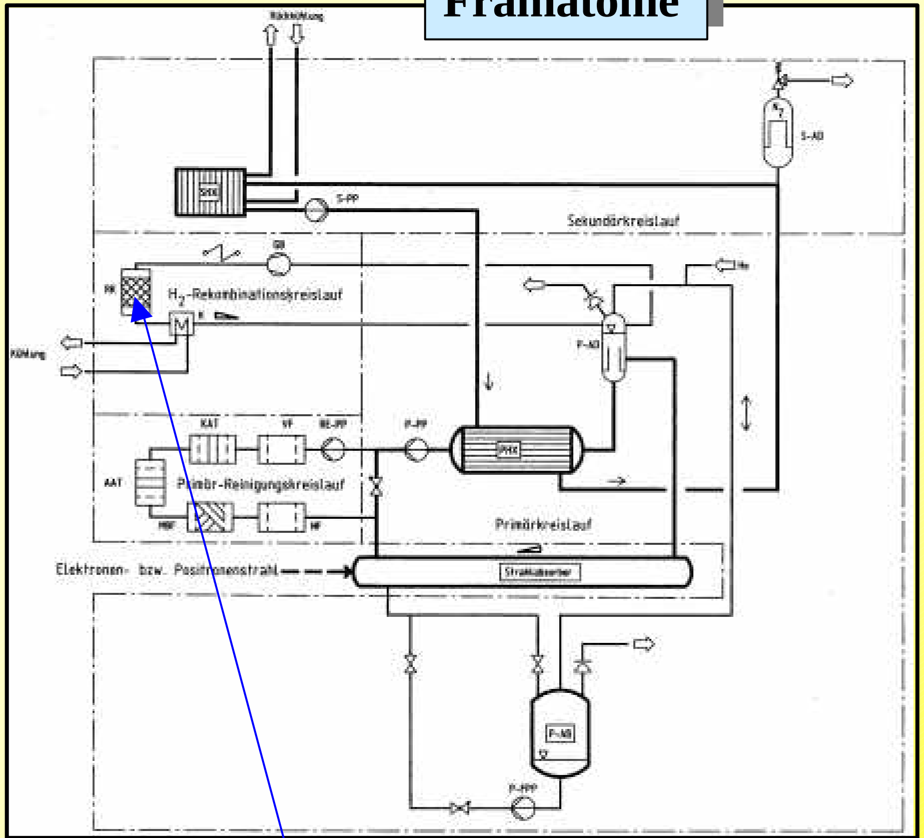
B1.2: External Water System - companies scheme

Fichtner



- hydrogen catalysor directly in water stream
  ® apparently more efficient
- mass flow in dump can be twice the external value (® internal heat extraction)
- hardware costs (incl. delivery & installation)
  » 3.7 M€ per water system

Framatome



- hydrogen catalysor in gas phase
- hardware costs (incl. delivery & installation)
  » 5.0 M€ per water system

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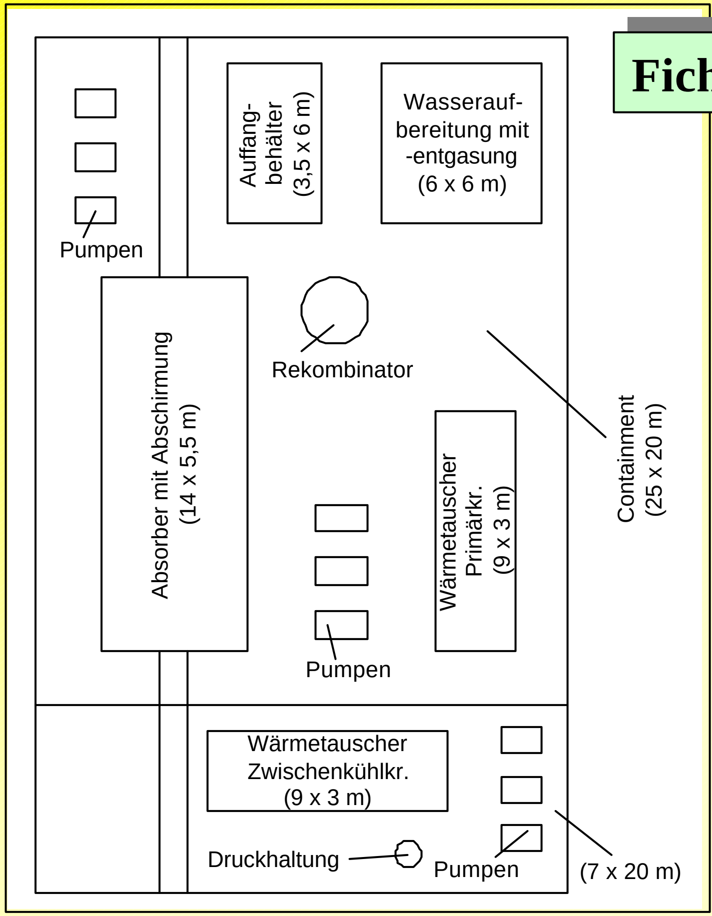
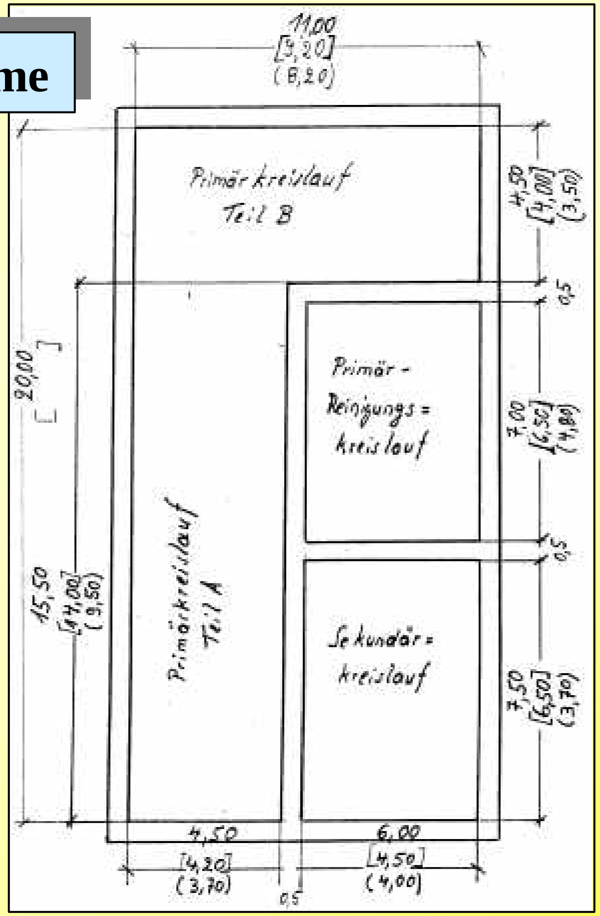
B1.3: External Water System - space requirement

Fichtner



Framatome

space required
in m, for:
18MW
[12 MW]
(2MW)

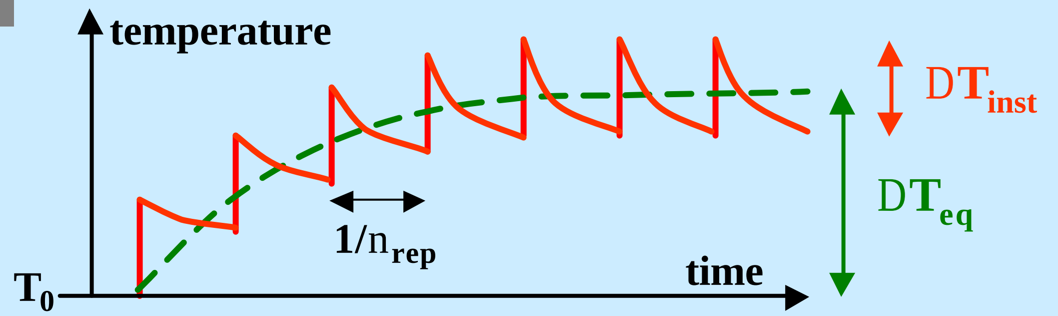


- **required space for 18 MW water system: 20m x 25m x 8m (w. dump, w/o. sec. loop) + 20m x 7m x 8m for secondary loop**
- **secondary loop outside of containment**

- **required space for 18 MW water system: area: 11m x 20m (w/o. dump) height: » 10m (storage container at deepest, recombiner at highest position)**

B2.1: Internal Heat Extraction - introduction

Heating Process



ΔT_{inst} : instantaneous temp. rise caused by energy deposition of 1 bunch train, $dE/dV(r,z) = c \times \rho \times \Delta T_{inst}(r,z)$, thermal diffusion within 1ms only 10μm in water

ΔT_{eq} : temperature rise assuming a time independant heat source S, with average power and spatial distribution given by subsequent bunch trains, $S(r,z) = 4Hz \times dE/dV(r,z)$

⇒ conservative estimation for the temperature at a given position $s=(r,z,\varphi)$:

$$T(s) \le T_0 + \Delta T_{eq}(s) + \Delta T_{inst}(s)$$; where T_0 = water inlet temp. (50°C)

Task

under the given external water mass flow of 140kg/s,

create a suitable water velocity field inside the dump vessel, in order to:

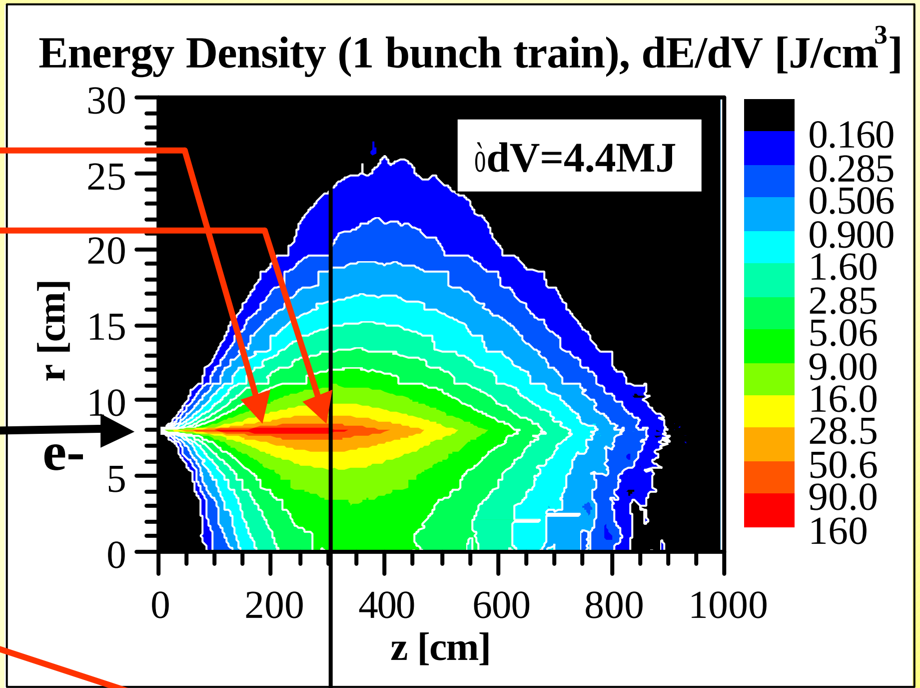
keep T(s) well below boiling point (180°C) at any position, i.e minimize $\Delta T_{eq}(s)$

B2.2: Internal Heat Extraction - the heat source

$DT_{inst}(r,z) = 1/(c \cdot r) \cdot dE/dV(r,z)$

Þ $(DT_{inst})_{max}$ = 40K @ r = 8cm, z » 200cm

Þ DT_{inst} = 28K @ r = 8cm, z » 300cm

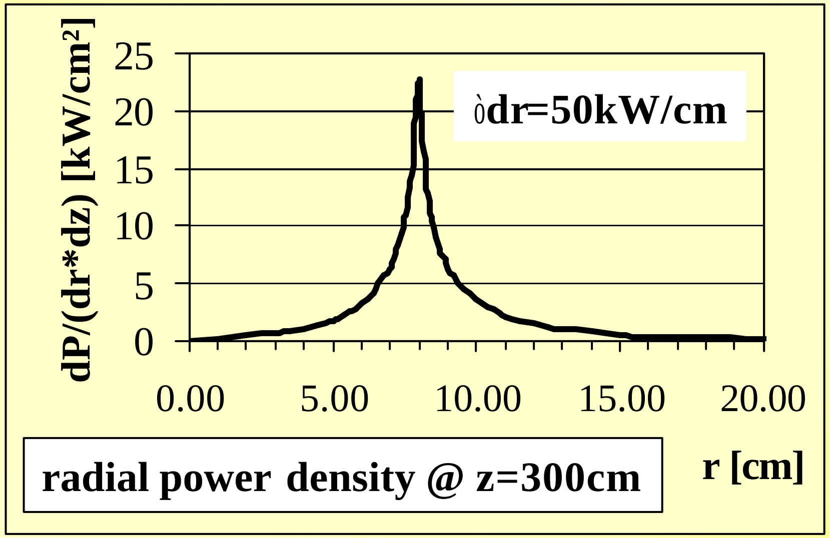


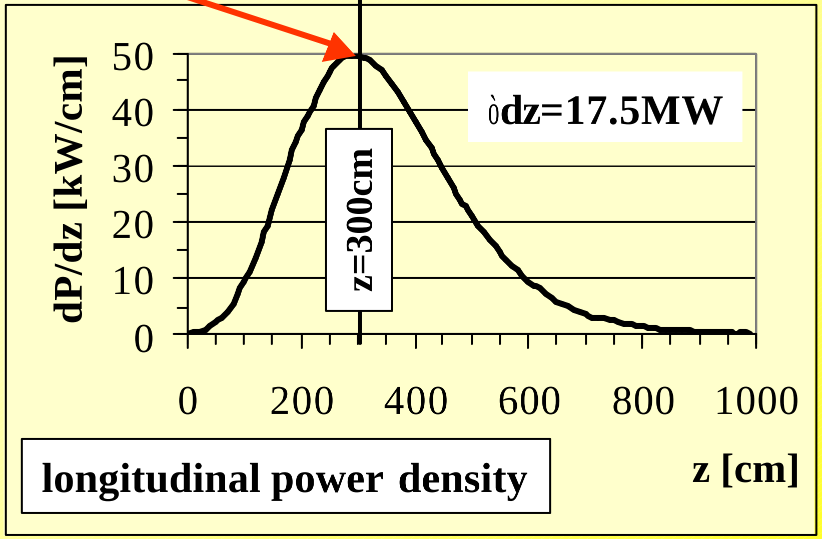
1 bunch train in water, 6.84×10^{13} e- @ 400GeV

$s_x = s_y$=0.55mm and fast sweep R_{fast}=8cm

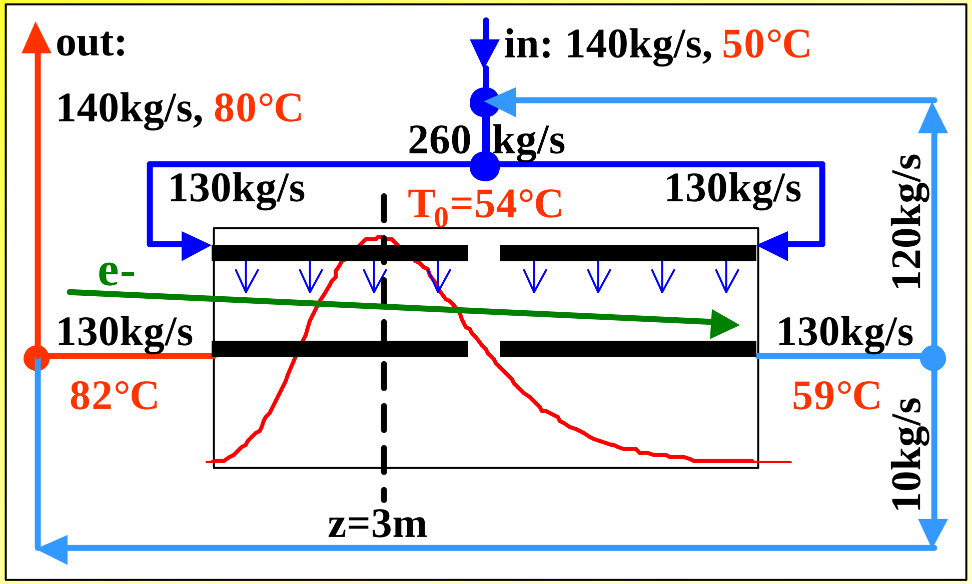
4Hz bunch train repetition:

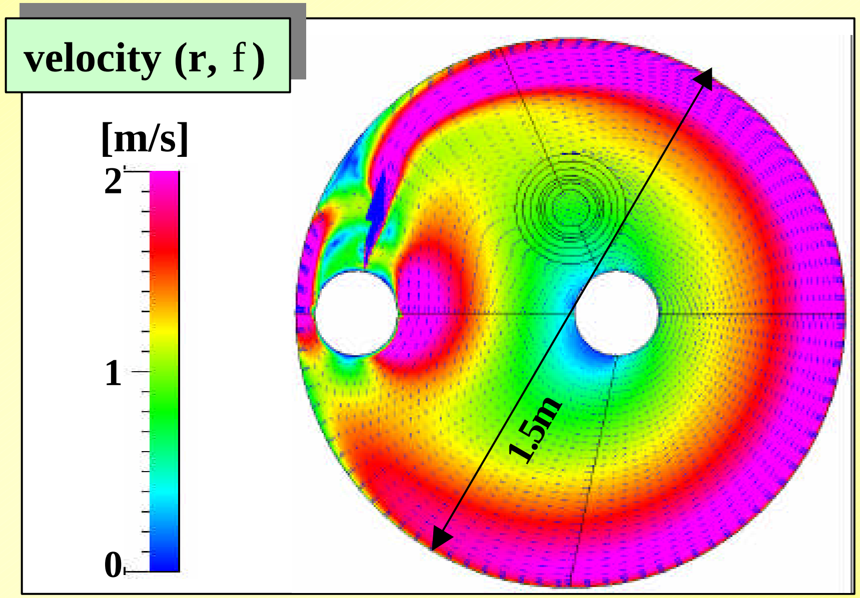
Þ $(dP/dz)_{max}$ » 50kW/cm @ z » 300cm



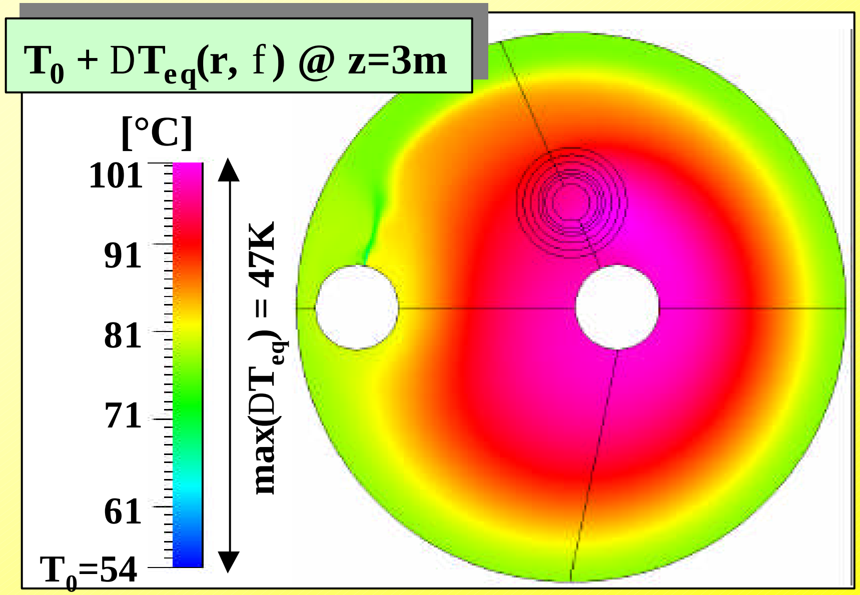


B2.3: Internal Heat Extraction - Fichtner scheme

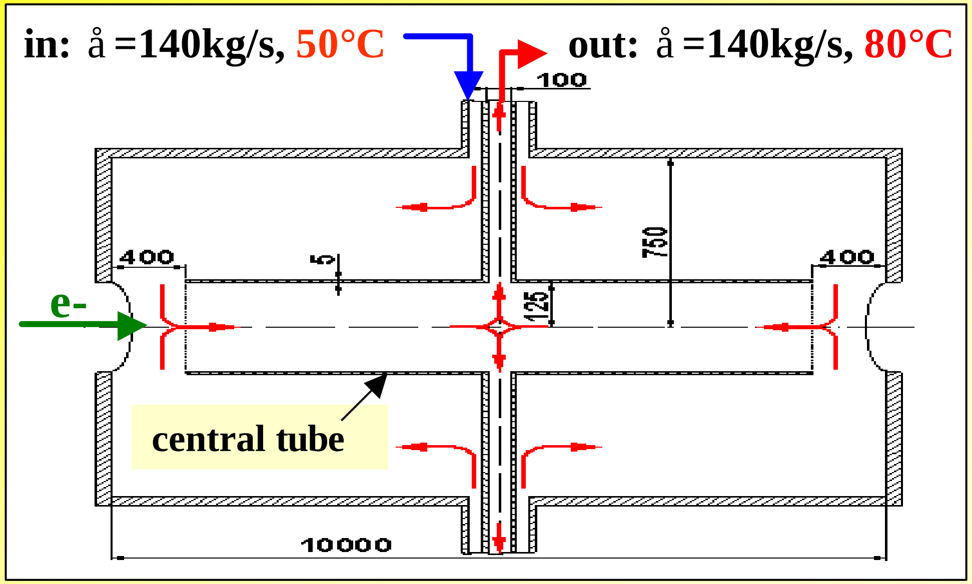


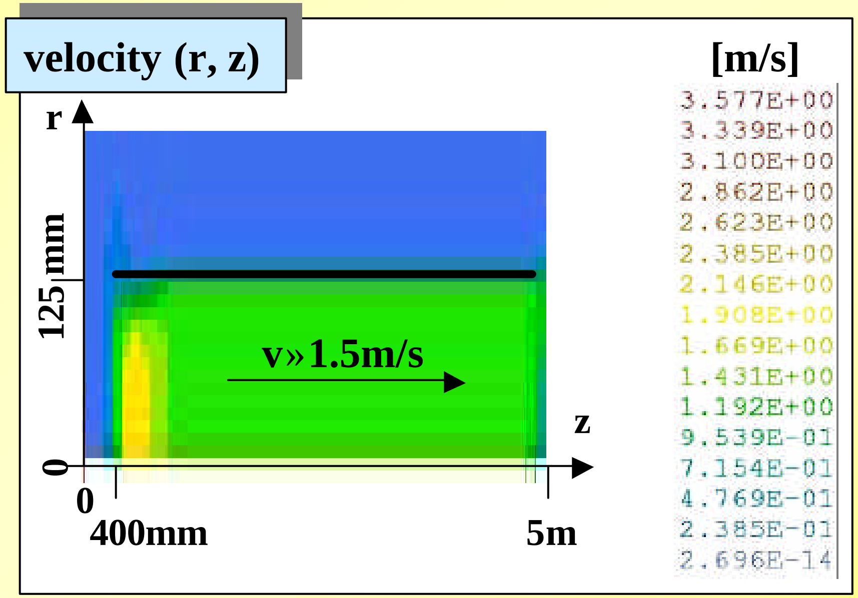


- vortex-like flow, velocity ¹ f(z), CFD code
- front / rear part split and water mixing
  Þ internal flow 140 to 280 kg/s, here 260 kg/s
- water velocity at inlet nozzle » 30 m/s !
  Dp (in-out) » 5 bar Û 130 kW pump power !
- 2d (r, f) stationary simulation at z=3m :
  T_0+max(DT_{eq}+DT_{inst}) = 54°C+47K+28K = 125°C
  well below 180°C boiling point



B2.4: Internal Heat Extraction - Framatome scheme VLS2

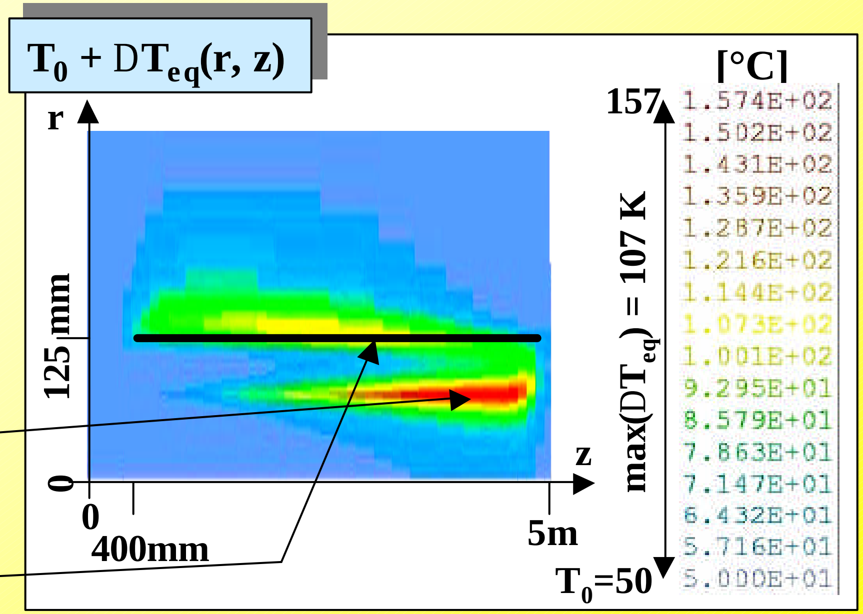




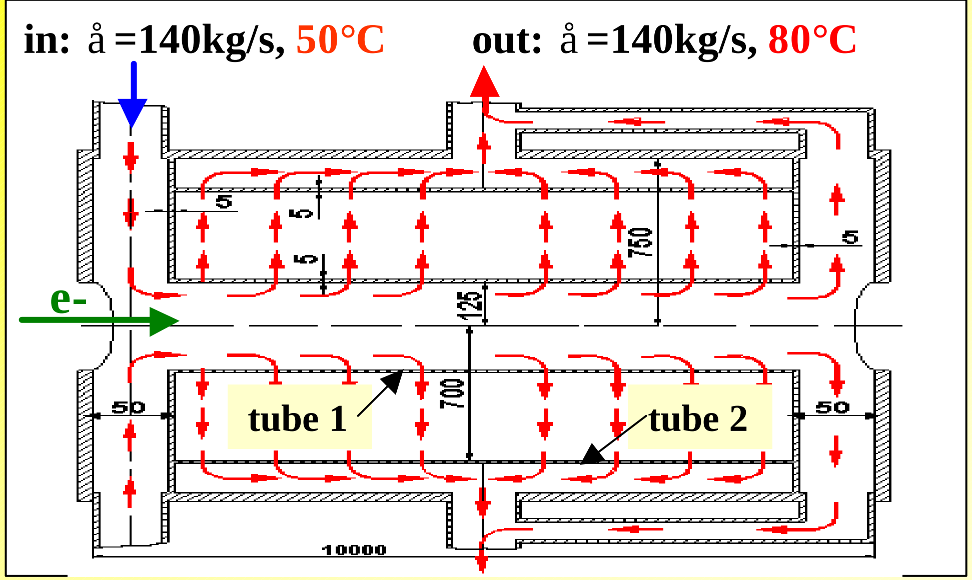
- long. flow, 3d-simulation, PHOENIX code
- internal flow = external flow = 140kg/s
- central tube: close to shower, 15mrad difficult
- Dp (in-out) » 0.2 bar Û 5 kW pump power
- max. water temp. is at z=4.6m, r=8cm

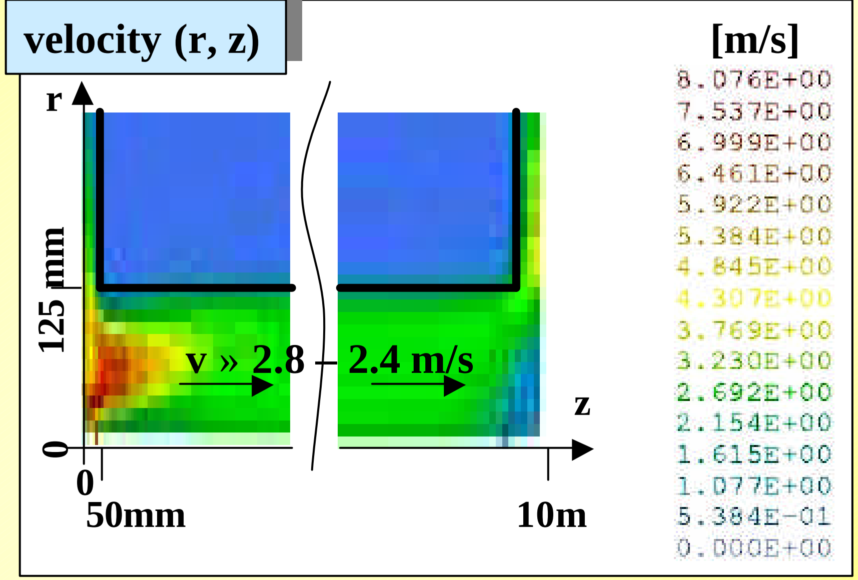
  T_0+max(DT_{eq}+DT_{inst}) = 50°C+107K+8K = 165°C
- max. tube temp. is at z » 3.4m, r=130mm

  T_0+max(DT_{eq}+DT_{inst}) = 50°C+62K+7K = 119°C



B2.5: Internal Heat Extraction - Framatome scheme VLQ2

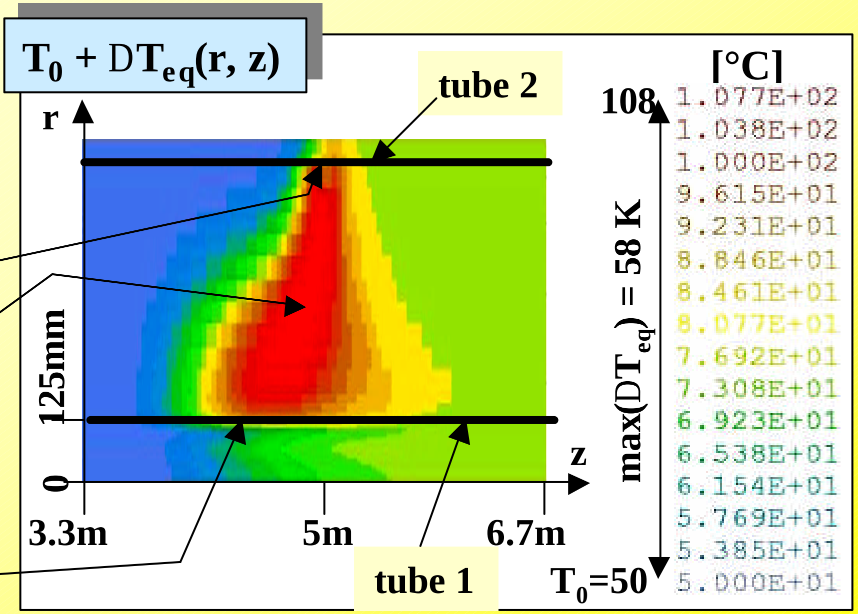




- long. + radial flow, 3d-sim., PHOENIX code
- internal flow = external flow = 140kg/s
- tube 1/2: 0.1/0.02% porosity ® 15% radial flow
- max. tube 2 temp., 50°C+45K+0K = 95°C
- max. water temp. between tube 1 & 2

  T_0+max(DT_{eq}+DT_{inst}) = 50°C+58K+0K = 108°C
- max. tube 1 temp. is at z » 4m, r=130mm

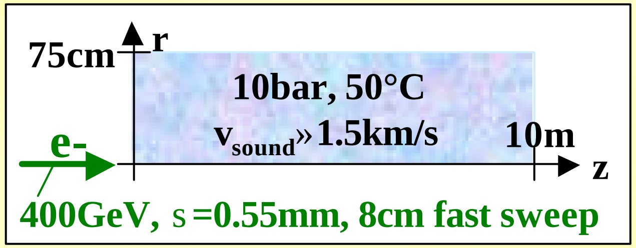
  T_0+max(DT_{eq}+DT_{inst}) = 50°C+34K+7K = 101°C



C1: Pressure Waves (work by TÜV-Nord)

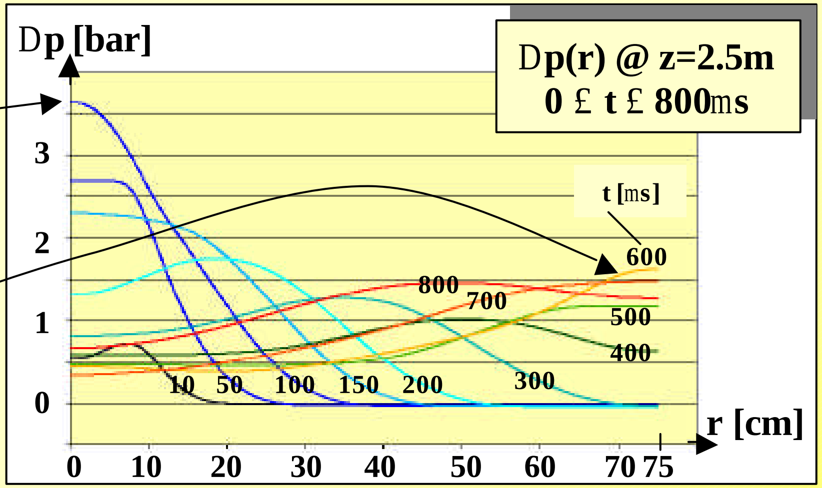
Assumptions

- consider 1 bunch train 860ms long as dc-beam
  source: S = 1/860ms x dE/dV for 0 £ t £ 860ms and S = 0 otherwise
- CFD code, no handling of phase transition: fluid ® vapour



Results

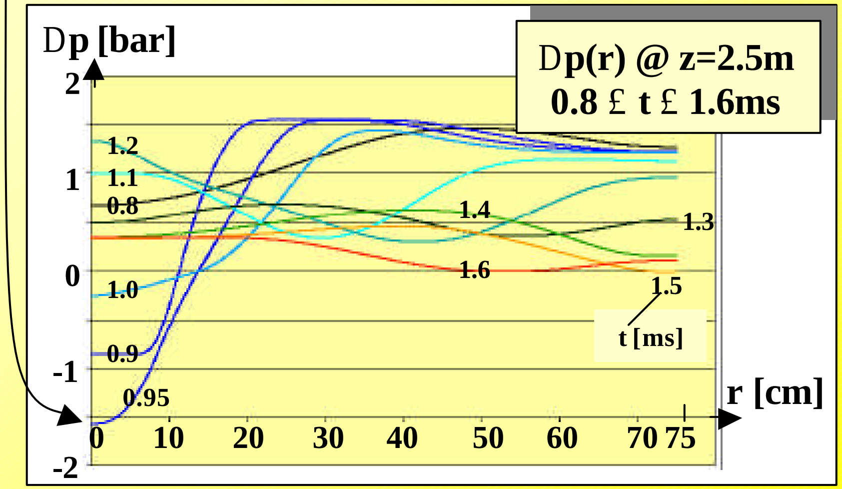
- in water: Dp$_{max}$ » 3.7bar near z-axis @ 100 ms
  Dp$_{min}$ » -1.6bar near z-axis @ 950 ms
  ® reduces boiling point & solubility of gases !
- at vessel cylinder: Dp$_{max}$ » 1.8bar @ 650 ms
- at front/rear face (windows): Dp$_{max}$ £ 0.5bar
- pressure wave decay to 0 after » 3ms



- <u>if heating gets near boiling temperature</u>

(simulated s » 6mm, no sweep, stop beam after 325ms)

® in water: Dp$_{max}$ » 9bar, Dp$_{min}$ » -6bar
at vessel cylinder: Dp$_{max}$ » 2.7bar
at front/rear face (windows): Dp$_{max}$ » 0.5bar
pressure wave decay to 0 after » 20ms



C2: Radiolysis

Fundamentals

- H_2O cracked by shower of high energy primary electron
- net production rate at 20°C / 1 atm (n.c.): 0.3 l/MJ H_2 and 0.15 l/MJ O_2 Û 0.27 g/MJ H_2O
  spatial distribution according to dE/dV profile
- solubility in 60°C water: H_2: 16 ml/l and O_2: 19.4 ml/l

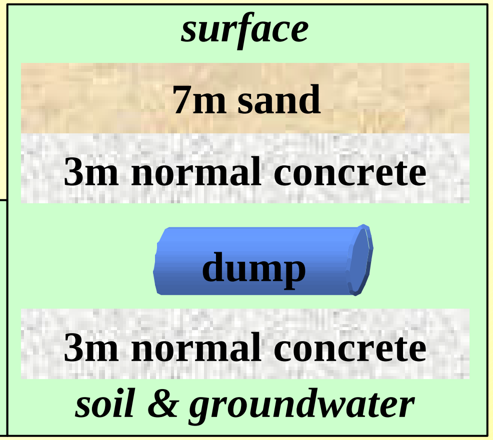
Our Case

- at 20 MW: 4.82 g/s H_2O Þ whole primary water ($30m^3$) would be radiolysed in 72 days !
  thus recombination: 6 l/s (n.c.) H_2 + 3 l/s (n.c.) O_2 ® 4.82 g/s H_2O + 58 kW (0.3% x P_{beam})
- solubility limit during 1 bunch train at 10 bar
  dE/dV £ 530 J/cm^3 for H_2 & dE/dV £ 1300 J/cm^3 for O_2 ; our case $(dE/dV)_{max}$=160J/ cm^3

so far it looks almost good, BUT H_2 control is a critical thing:

- if <u>not all</u> H_2 is recombined, amount of solved gas ¹ 0, outgassing & accumulation at special locations not excluded <u>Þ danger of explosion (e.g. nuclear power plant Brunsbüttel)</u>
  - therefore recombination in gas-phase without expansion doubtful ® *Framatome proposal*
  - recombinators directly in return pipe of dump vessel seems better ® *Fichtner proposal*
- solubility during bunch train passage can be exceeded locally, since:
  negative Dp, DT_{inst} rise, amount of solved H_2 ¹ 0
  <u>Þ danger of H_2 gas bubbles and induced pressure waves comparable to local boiling</u>

D1.1: Radiation Handling



Shielding of water vessel towards soil, groundwater and surface

- soil & groundwater: 3m normal concrete or equivalent
- surface: 3m normal concrete or equivalent + 7m sand or equivalent

Activation of primary circuit, 18MW, $30m^3$ water

$A(t)=p\cdot(1-e^{-l\cdot t})$	p ° production rate = A_{sat} l ° $\ln 2/t_{1/2}$

- in water besides short lived isotopes also ^{7}Be , ^{3}H=T, ...

^{3}H: 20keV b$^-$, $t_{1/2}$=12a, A_{sat} =280TBq (0.76g, 2.8l T_2 or 5g HTO), A(5000h)=9TBq, A(10a)=120TBq

- no outside dose rate, but problem if released due to leakage or maintainance !

^{7}Be: 478keV g, $t_{1/2}$=54d, A_{sat} =120TBq

- main contributor to dose rate

  equal distribution ® 300mSv/h at surface of component ! , 50mSv/h in 50cm distance
- accumulation in resin filters, but also adsorption on circuit surfaces (esp. heat exchanger)

  ® local shielding

- 20mm thick stainless steel dump vessel gives » 400mSv/h on its axis (5000h op., 1month wait)

  ® regular inspection of vessel (welds, ...) from inside by persons definitely excluded

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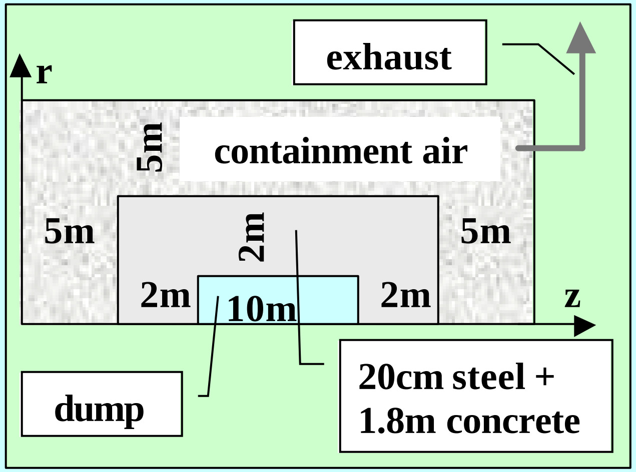
D1.2: Radiation Handling

Activation of containment air, 18MW, » 3000m³ air

- necessity of closed containment, „closed“ Û under-pressure by continous exchange rate of » 1/h and controlled exhaust

	A_{sat}	A(5000h)	specific A @ saturation [Bq/m³]		
			w/o air exchange	with ex-change 1/h	allowed limit
^3H	1.4GBq	43MBq	470k	3	1k
^7Be	390MBq	370MBq	120k	70	6k



Þ looks fine except for: short lived need „delay line“ of » 1h and leakage of primary circuit !

Scheduled opening of primary circuit, 30m³, 100TBq of ³H

- flush water in storage tank, » 100l remain (0.1mm on 1000m²), vent system with dry gas via 95% efficiency condenser Þ 5l » 10GBq tritium have to be released to outside air
- meet the limit of 1kBq/m³ needs dilution with 10^7m³ and takes 1000h=42days! with 10^4 m³/h

Þ extrememly strong recommendation to use a chimney ³ 20m

Dismantling of activated system after final shut down, 20 years 200TBq of ³H

- primary water solidifying as concrete Þ 5000 barrel (200l, 40GBq)
- steel components (150t, £200Bq/g) & concrete shielding (1500t, £10^6Bq/g)

} S ³ 50M€

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E: Concluding Remarks

- external heat extraction no problem
- internal heat exraction feasible, preference on azimuthal water flow (Fichtner scheme)
- radiolysis including local and instantaneous effects represents a severe risk
  ® explosion of a high activated water system
- unknown level of dynamic pressure due to local boiling or local outgassing of radiolysis gases
- maintainance / opening of primary circuit
  ® without chimney difficult to present an approvable concept
- beam window for vacuum / water transition 10bar static + 0.5bar dynamic
  ® no reliable design exists, no concept in emergency case of window break
- dismantling costs not negligible

Compared to solid C-Cu dump the water dump looked quite attractive at first sight, BUT ...

... This concept has still its inherent risks, which will make it difficult to „sell“ it as reliable, safe and robust.

Þ Critics of the LC-project will probably focuse on the beam dump to attack the approval procedure