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Modeling & Analysis of Liquid Deuterium-Water Reactions

by

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This Presentation Will Highlight

- o Overview of LD_2-Water reactions & their connections to research reactors with cold sources
- o Some key features and ingredients of vapor explosions in general
- o Examination of results of 1970 experiment at Grenoble Nuclear Research Center
- o Thermodynamic evaluations of energetics of explosive LD_2-D_2O reactions

**** This presentation will concentrate only upon the technical aspects of LD_2/LH_2 Water reactions; it is not intended to draw/imply safety-related conclusions for research reactors ****

Notes on Vapor Explosions

******* It is well-known from several Freon-water, LNG-water experiments and experiences that such interactions can be explosive under the right circumstances *******

o Vapor explosions (also referred to as FCIs) occur (if they do so) in 3 stages:

- Intimate premixing of hot and cold fluids
- Triggering to initiate film collapse and dispersion --> explosive heat transfer
- Propagation through mixture ---> pressure buildup and mechanical work

o An LD_2-Water explosion would fall in the general category of FCIs where water is now the hot fluid

o Important effects and features to keep in mind are:

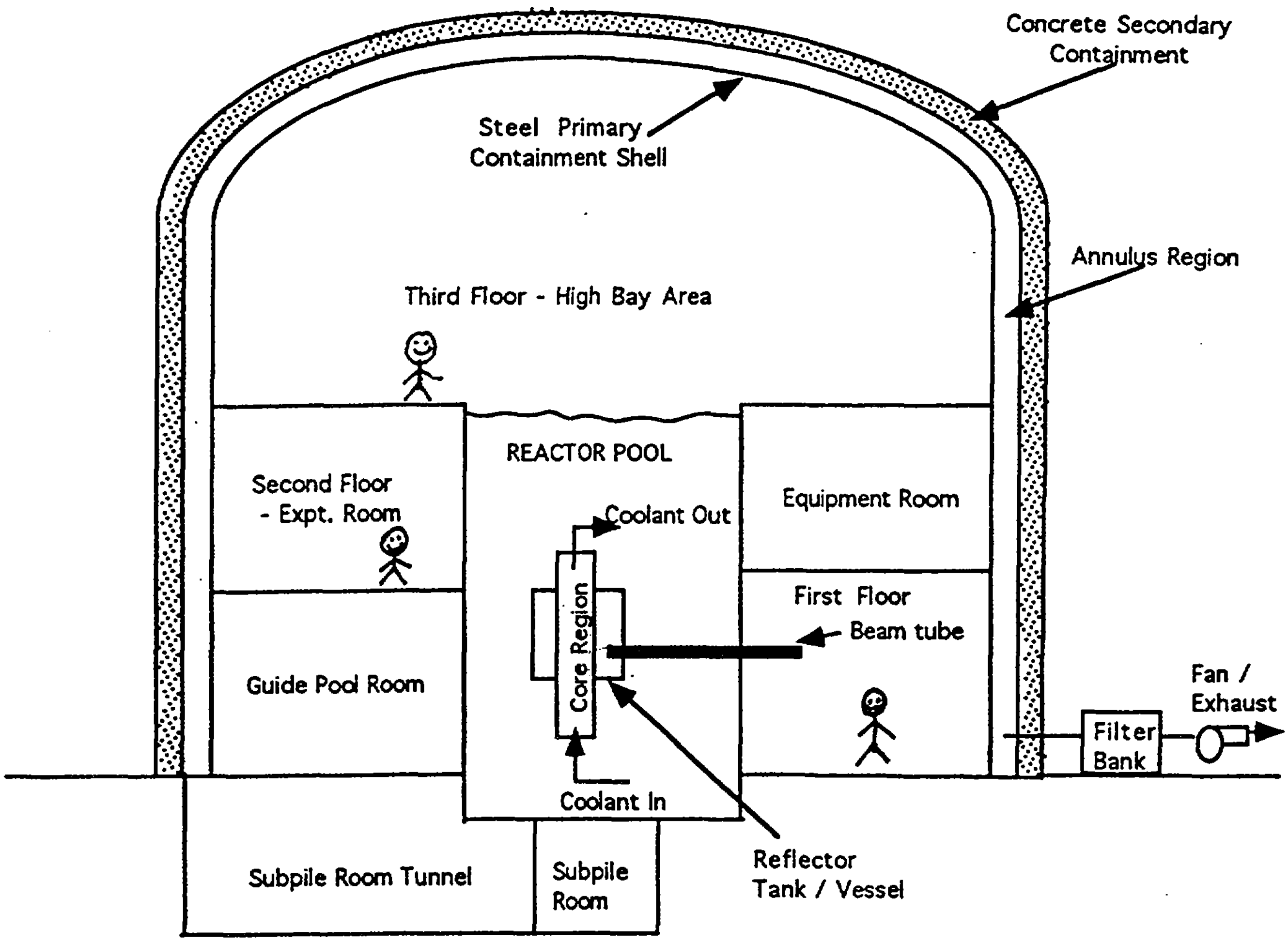
- Initial contact mode (e.g., injection, stratification, radial egress, etc.)

- Scale effects (small quantities usually need robust external triggering compared with large scale explosions)

- Thermodynamic states of hot and cold fluid

- Geometry of reaction zone (inertial constraint)

ANS CONTAINMENT



Grenoble Experiments

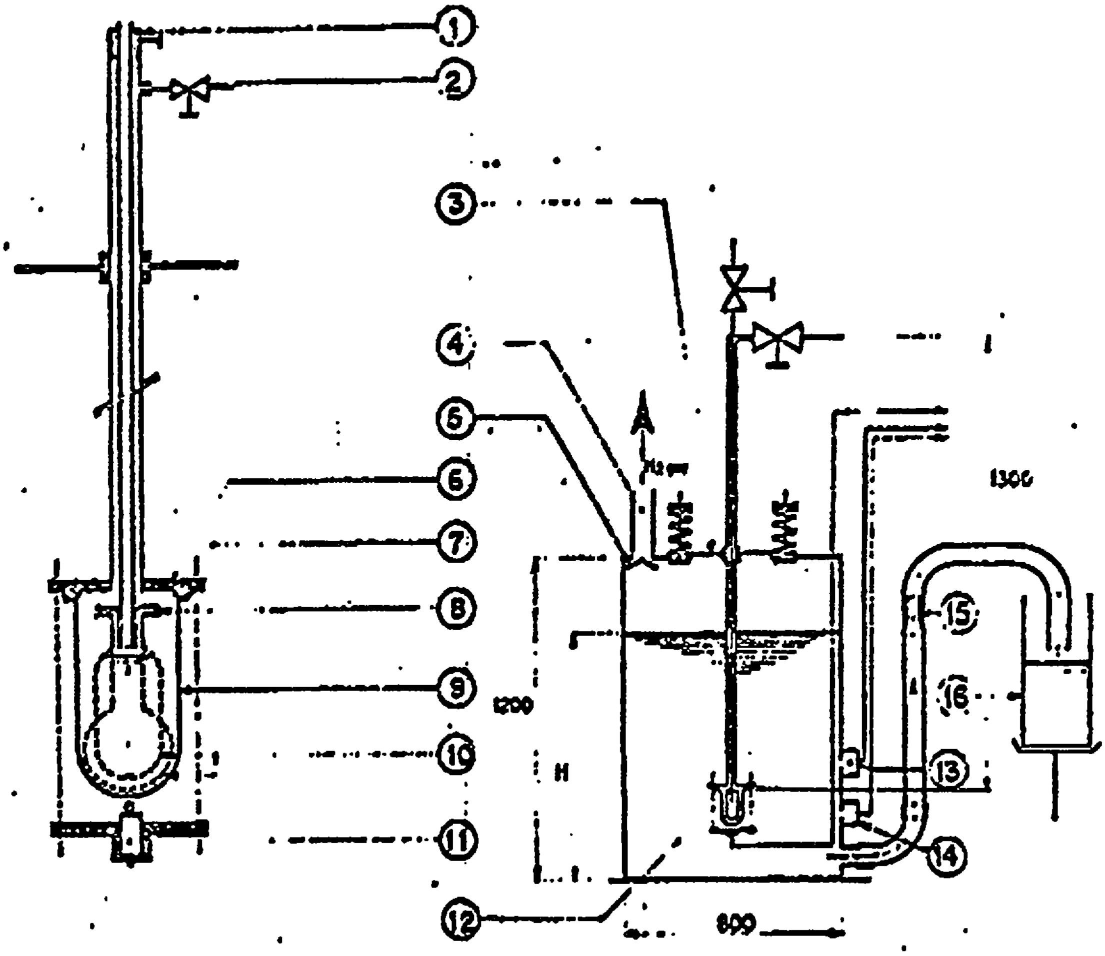
- o Geometry was carefully engineered to represent a scaled-down representation of ILL cold source within the reflector tank
- o Experiment parameters vs ILL reactor cold source

Parameter	Experiment	ILL Reactor
-Cold source fluid	LH_2	LD_2
-Source volume (L)	.025 to 1	38
-Source geometry	double walled (glass)	double walled (aluminum)
-Distance from source to reflector tank (m)	0.4	0.7

- o Instrumentation
  - Pressure taps at walls (response time ?), visual & camera film (<200 fps)
- o Experiment types

1) Impact hammer induced double-wall perforation ---> No explosion
2) Internal pressure buildup-induced forced ejection --> Explosive reaction

TEST CELL OVERALL VIEW



1. Direct passage valve
2 Vacuum plug
3. Valve
4. Stack
5. Deflector
6. Strap
7 Rubber gasket
8. Strap and O ring
9. PYREX vacuum bell
10. PYREX container of LH2
11. Striker
12. Water
13. Membrane manometer
14. Piezoelectric manometer
15. Venturi
16. Container

Figure 1. Schematic of Experimental Facility (dimensions in mm)

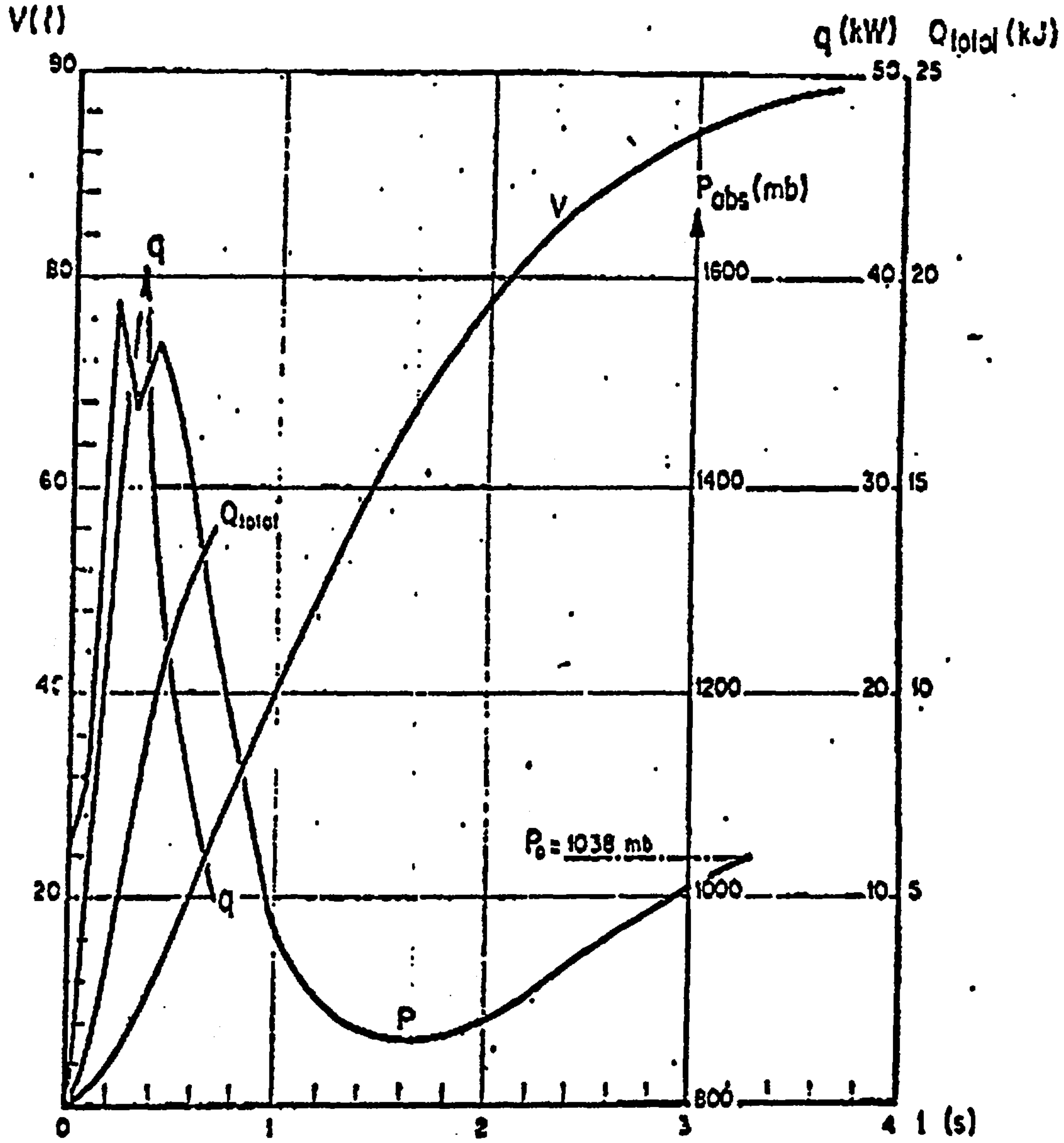


Fig: 4 – V_0 = 236 cm^3 LH_2 , sans ciel.

MODE OF CONTACT IS IMPORTANT

o Several Type 1 experiments were conducted by breaking the walls locally using an impact hammer

- No explosions occurred, although significant vapor is formed over 1-3 s
- Localized breakage of walls leads to significant bubbling, and relatively gradual mixing with water through "slits" causing vaporization of LH_2

---> *Such a contact mode can not be expected to result in explosions as the principal criterion of premixing with hot fluid is not present; Grenoble experiments clearly demonstrate this aspect.*

o Type 2 experiment gave rise to explosive interaction between LH_2 & Water

- Overheating and pressurization to 1.5 MPa by breaking the vacuum led to bursting of walls and forced ejection into the bulk coolant
- Excellent premixing followed by localized spontaneous triggering is evidently sufficient to cause explosive thermal energy transfer and vaporization of LH_2 **** No data are given on pressure traces, etc. ****

---> *Contact modes that force premixing will likely lead to explosions*

Note: 1 ml of LH_2 at 20.3 K = 55 ml of gas at 20.3 K = 850 ml of gas at 293 K

ENERGETICS OF EXPLOSIVE LD_2-WATER REACTIONS

- o MODELING OF ENERGETICS CAN BE DONE MECHANISTICALLY & ALSO USING THERMODYNAMIC MODELS

  - But, mechanistic models for modeling cryogenic fluid-water explosions are not well developed

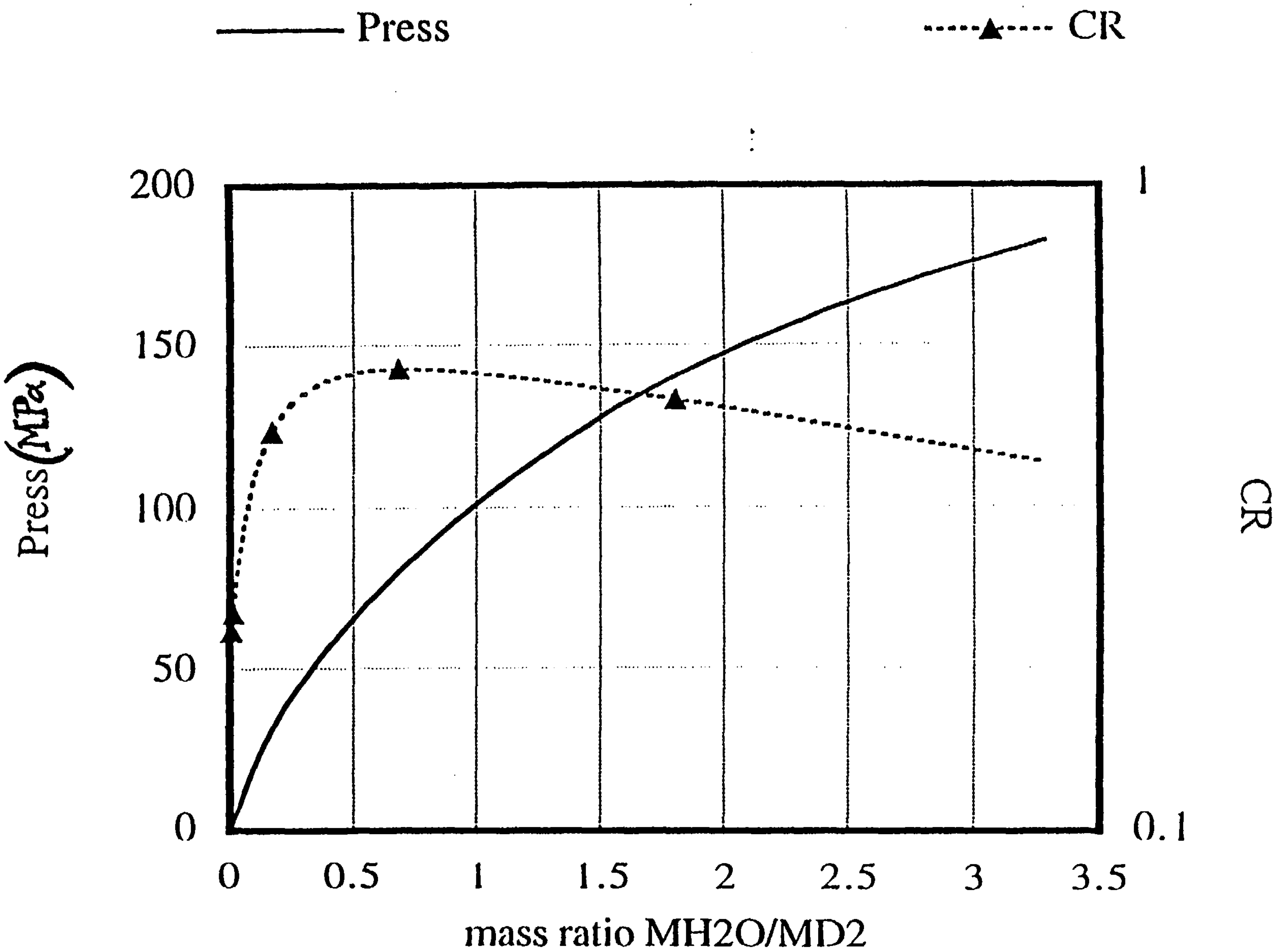
  - Thermodynamic models of vapor explosions can be used to provide physically bounding estimates (but should be used with caution since perfect mixing is assumed and no directional effects are considered)

- o WE HAVE UTILIZED THERMODYNAMIC MODELS (to evaluate reasonable upper bound estimates of pressurization, and thermal-to-mechanical energy conversion for Advanced Neutron Source beyond design basis accident studies)

  - Hicks-Menzies model: Essentially adiabatic mixing followed by isentropic fuel-coolant expansion

  - Board-Hall model: Essentially simulation of C-J shock front to a given pressure followed by isentropic fuel-coolant expansion

Note: Actual properties of LD_2 were utilized; work is preliminary



Variation of Pressurization (Press) and Conversion Ratio (CR) with Mass Ratio (Hicks-Menzies Approach)