Steam Condensation Induced Water Hammer Phenomena, a theoretical study

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Outline

- *Introduction*

  the Hungarian complex facility & applied two-phase flow model

- *The former apparatus*

  measurements & theoretical results & mechanism & quasi-validation of model

- *Recent works*

  measurements & new theoretical results, new features

- *Summary and Outlook*

Introduction

Republic of Hungary
Population 10 million
Area 93 square Km
GDP/Capita $15,542

In Hungary: 4 operating units of VVER-440/V213 Russian type PWR at Paks site, 440MWe, 6 loops,
~37% of the home-produced e-power

Our Institute(AEKI): consulant for NPP works for authorities
has a researh reaktor (3MW)
complex experimental facility
reasearch in material sciences, thermohydatrulics, fuel, and chemistry

A PMK-2 Integral facility

There are 10 nuclear reactor models around the world (e.g. LOFT, ROSA, PMK2)

Volume rato 1 : 2070 for
Paks National Nuclear Reaktor primer loop,
Russian type VVER-440/V-213
many similarity numbers are the same
CORE 19 electrically heated rods
Heating power: 664 kW

~ 55 termo-hydraulic tests were done in the last 20 years, warm, cold leg breaks, LOCA, code (Relap, Cathare, Athlet) validation

There is a Book available, See later

Introduction of the WAHA model

- 1Dim surface averaged, 6 equation model
- mass, momentum, energy balance equ. for both phases

$$\frac{\partial \vec{\psi}}{\partial t} + \underline{\underline{C}} \frac{\partial \vec{\psi}}{\partial x} = \vec{S} \qquad \vec{\psi} = (p, \alpha, v_f, v_g, u_f, u_g)$$

- Single pressure model
- Relap5 based Model, with different numerics
- 6 Equ. Model Widely used in the nuclear industry
- Realistic water-steam table, correlations for both phases
- Simplified Flow Maps
- Source Code available Fortran 90 J. Comp. Phys. **136**, 503 (1997)
- Recently we modify for Liquid Metals (Proton caused heat shocks in Mercury target in Spallation Sources) Eur. Phys. J. B **66,** 419–426 (2008)

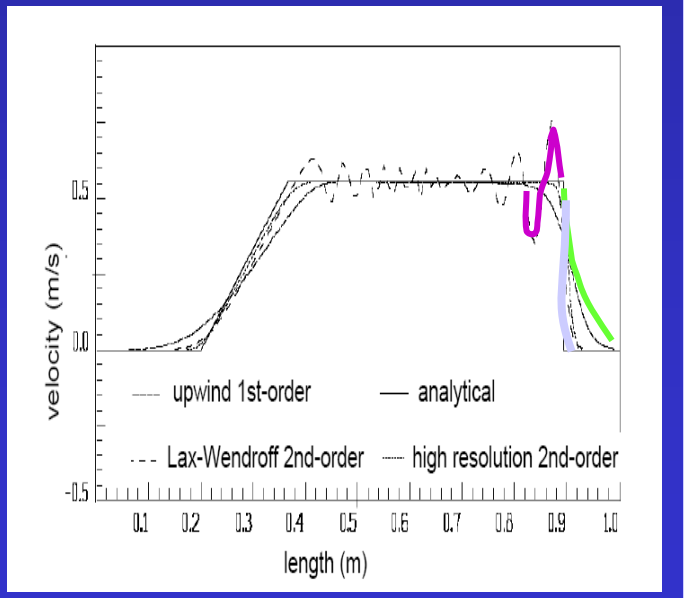
I will give a talk on IWSMT 10 conference in a week in Beijing

Idea of the numerical method

- Hyperbolic partial dif. equ. systems ⟶ non-continous solutions
-
- (jump initial condition is conserved in time)
- Special numerical method is needed

$$\frac{\partial \vec{\psi}}{\partial t} + \underline{\underline{C}} \frac{\partial \vec{\psi}}{\partial x} = \vec{S}$$

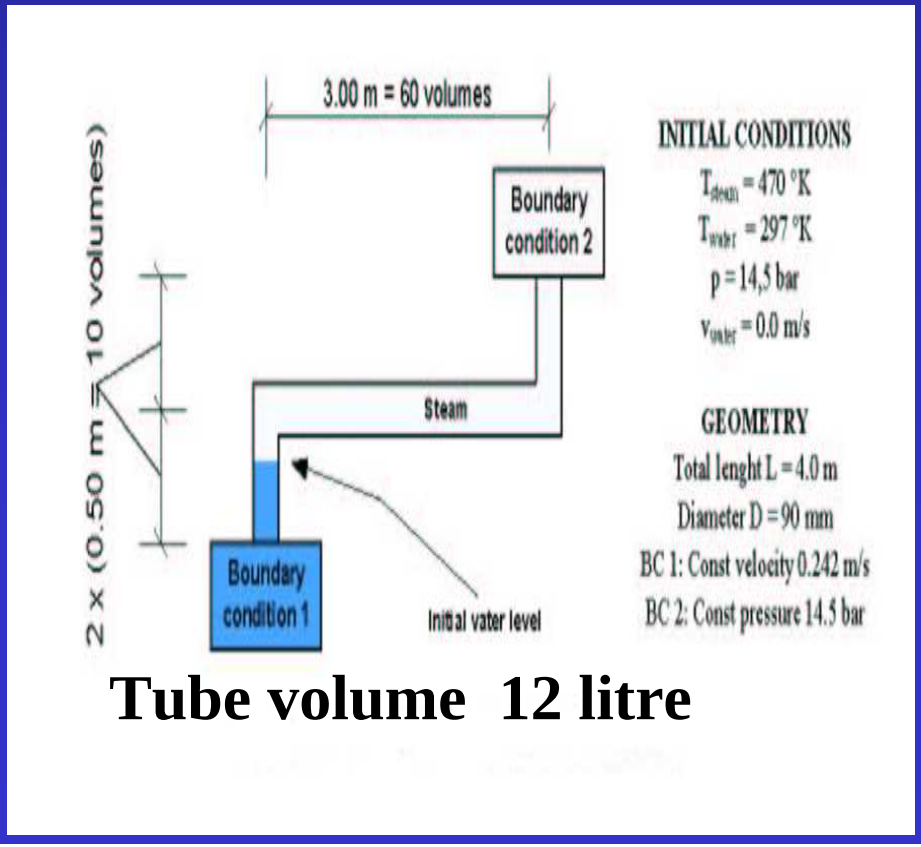
- Pure 1st order method smears discontinuity
- Pure 2nd order creates unphysical oscillations
- Mixed method gives physicaly correct answer (flux limiters)



The first experimental apparatus

supplied with 12X12 void mesh sensor, void probes, thermo-couples, high resolution electronics

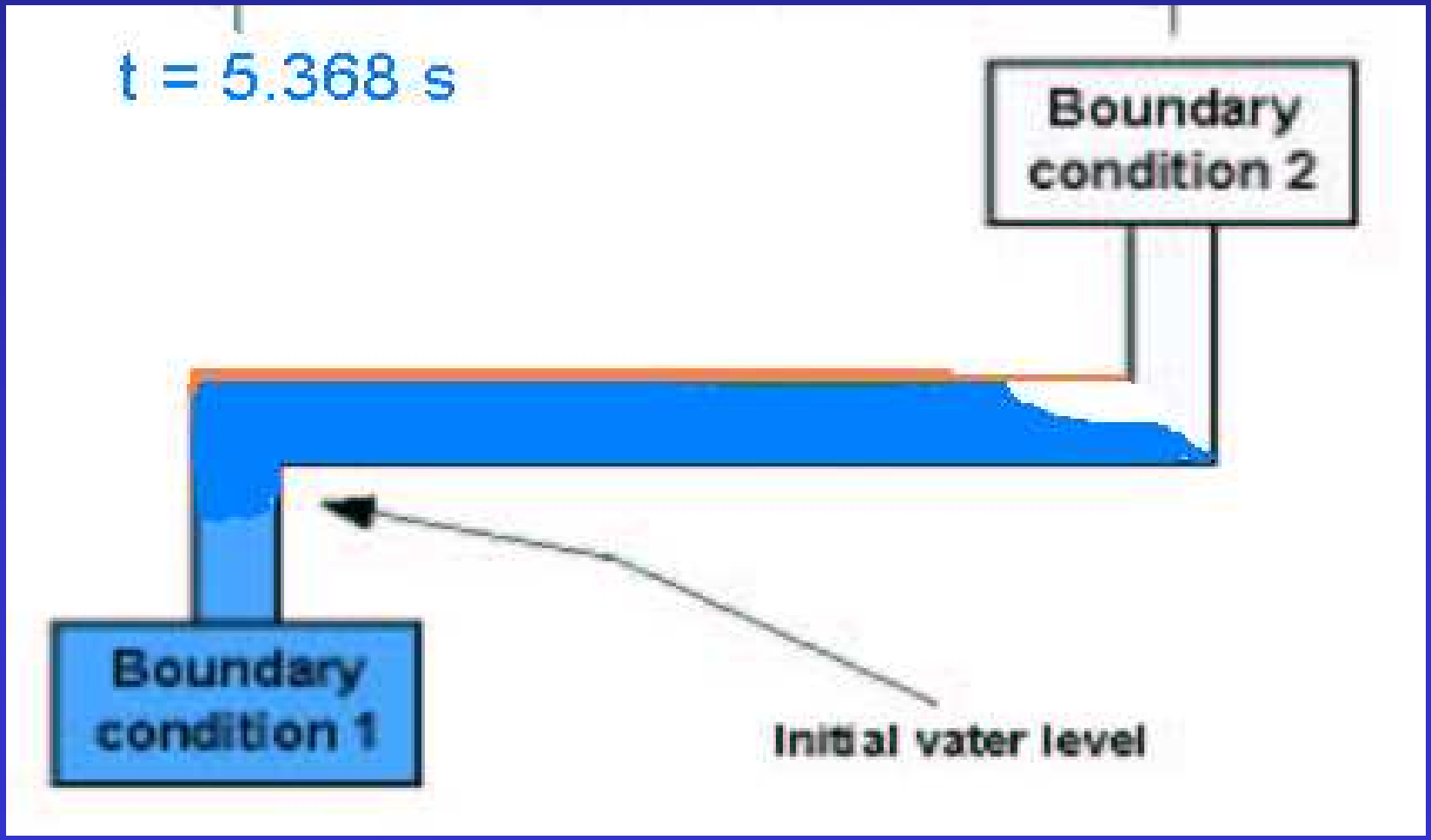
(photo is without thermal isolation, and the model scheme in numerical simulation)



Tube volume 12 litre

The mechanism for steam condensation induced water hammer

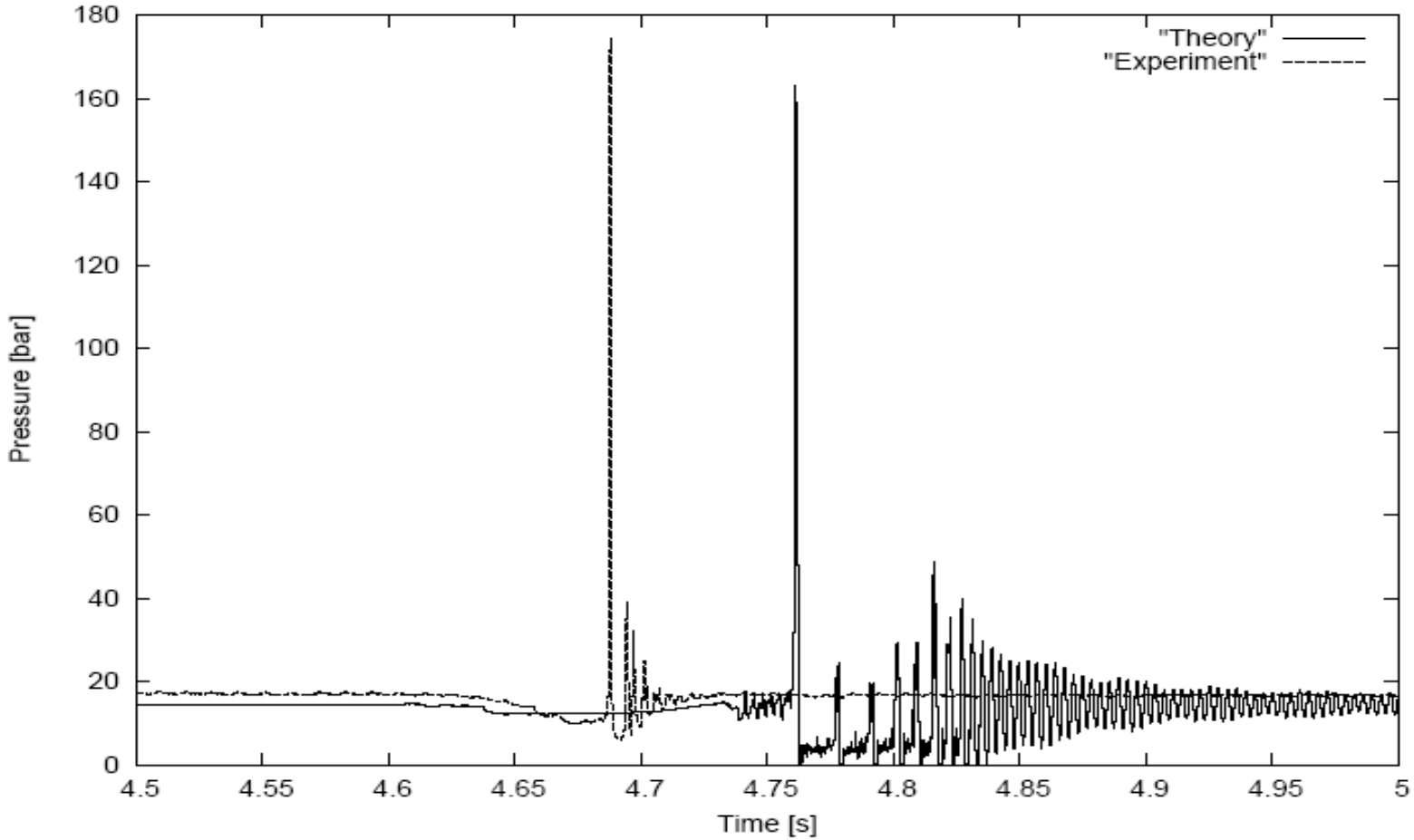
(some figures, poor man's animation)



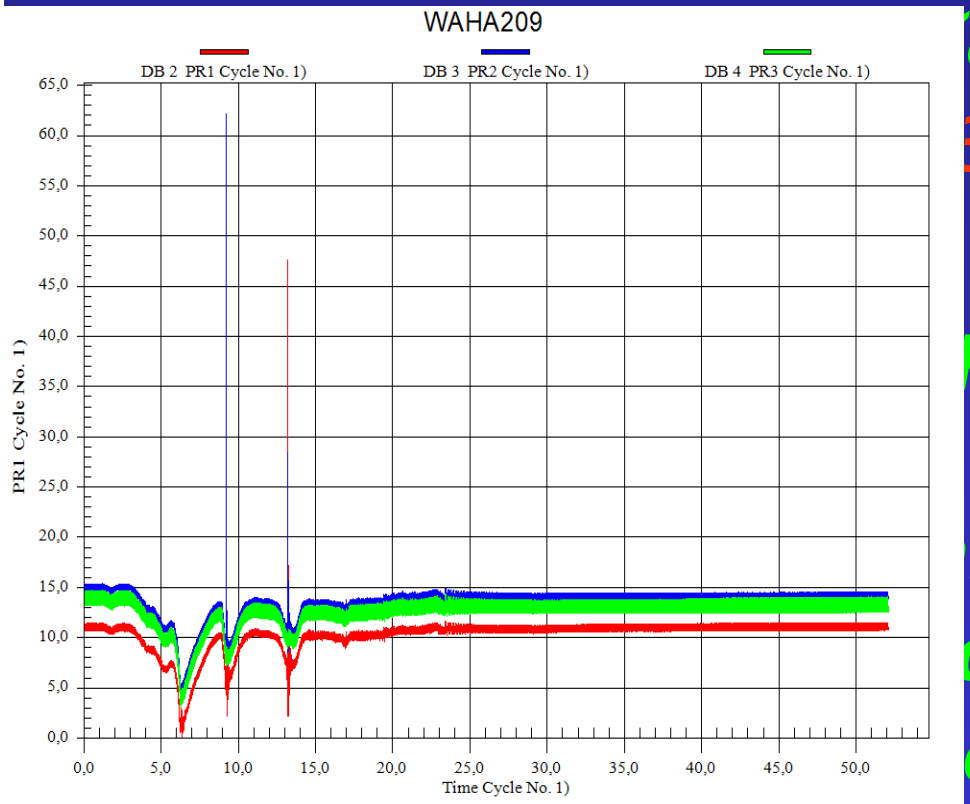
Analysis of the pressure peaks

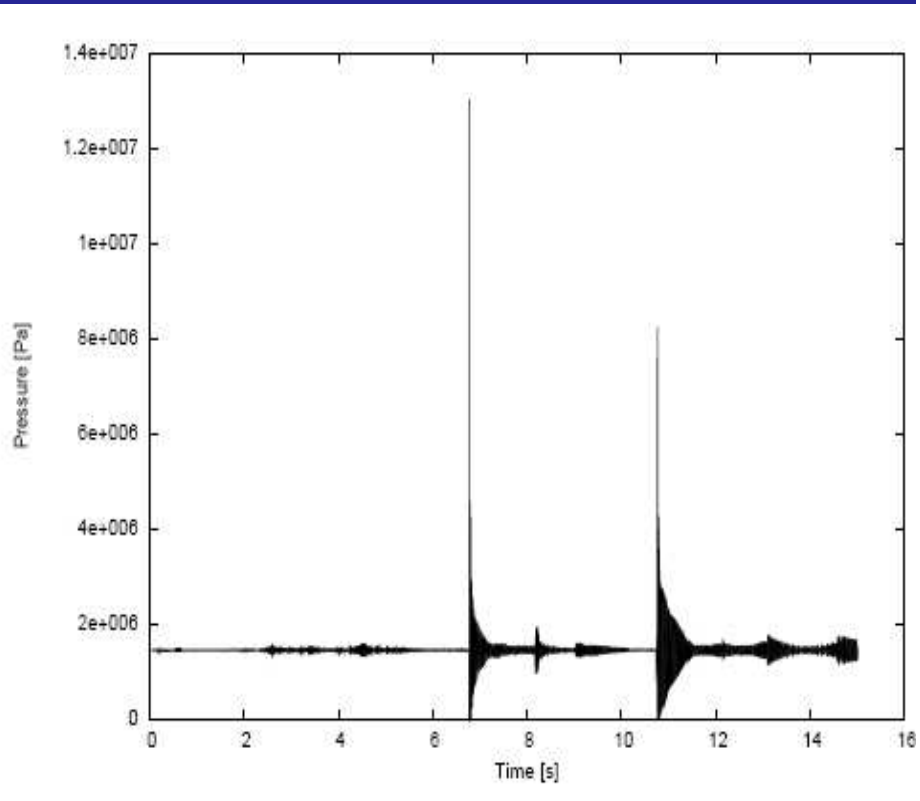
(all the correlations/know-hows are needed)

Nucl. Eng and Des. 240, 146, (2010)



Additional tests, results





See *" 9003 Experimental and Theoretical Study of Steam Condensation Induced Water Hammer Phenomena "*
Proceedings of the 2009 International Congress on Advances in Nuclear Power Plants, Tokyo, May 10-14 2009

Necessary and sufficient conditions for CIWH

Steam bubble collapse induced water hammer events happen if the following six conditions meet:[13]

1) the pipe must be almost horizontal (max. pipe inclination must be less than 5 degree)
2) the subcooling must be greater than 20 C^{o}
3) the L/D (length-to-diameter ratio of the tube) must be greater than 24
4) the velocity must be low enough so that the pipe does not run full, i.e. the Froude number must be less than one
5) there should be a void nearby
6) the pressure must be height enough so that significant damage occurs, that is the pressure should be above 10 atmospheres.

Only necessary conditions!!!

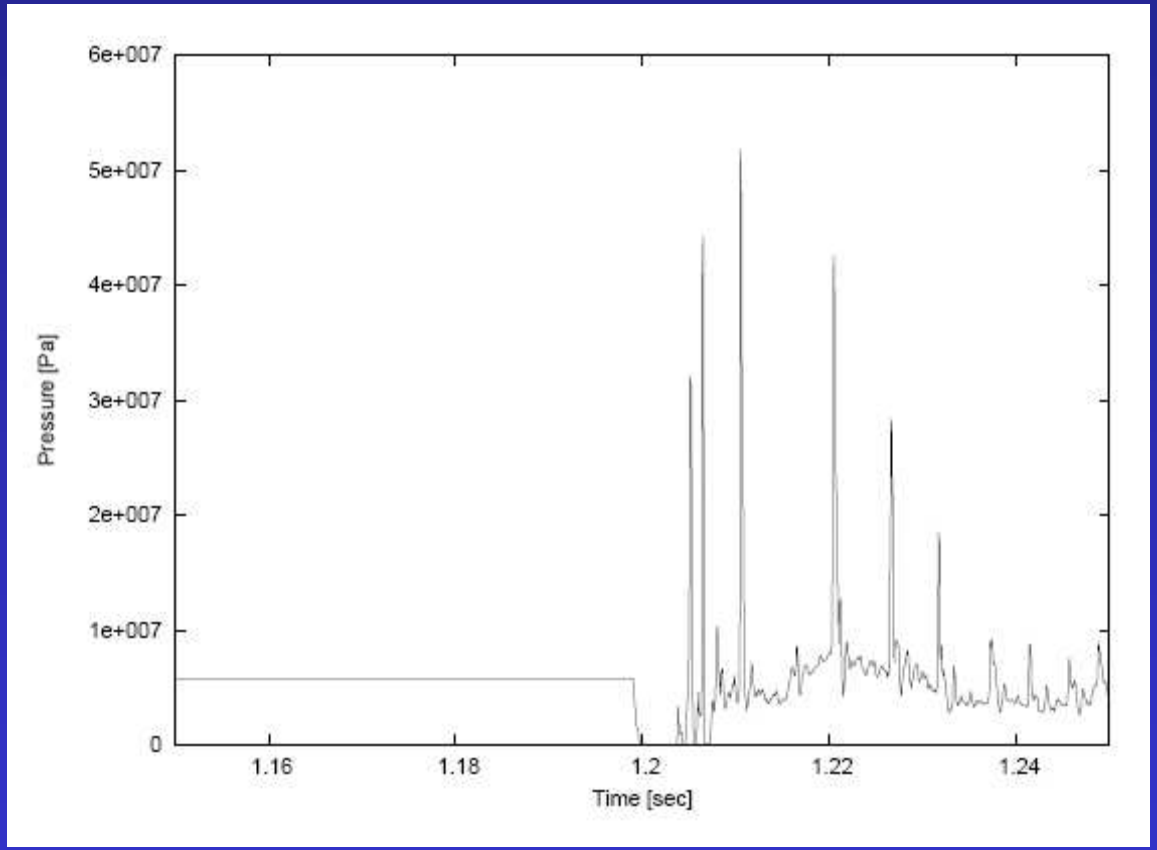
Screening Reactor System/Water Piping Systems for Water Hammer P. Griffith
Repaired for Division of Systems Technology
Office of Nuclear Regulatory Commision
Washington
DC, 20555-0001
NRC Job Code J6008
NUREG/CR-6519

Examined Pipelines in the National Power Plant VVER/440

Pipe Section	Steam Pressure (bar)	Steam Temperature (K)	Pipe Length L (m)	Pipe Diameter d (m)	Flooding Velocity (m/s)	Water Hammer Yes/No
1	58	546	5.3	0.1	0.63	Yes
2	58	546	3.6	0.05	2.55	No
3	58	546	8.7	0.05	2.55	No
4	110	591	8.7	0.05	2.55	No
5	7	438	6.9	0.23	0.8	No

in all cases all the 6 the necessary conditions are fulfilled

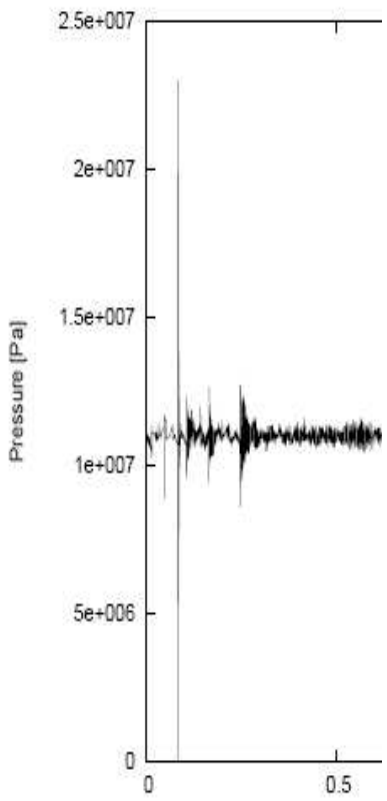
Positive result

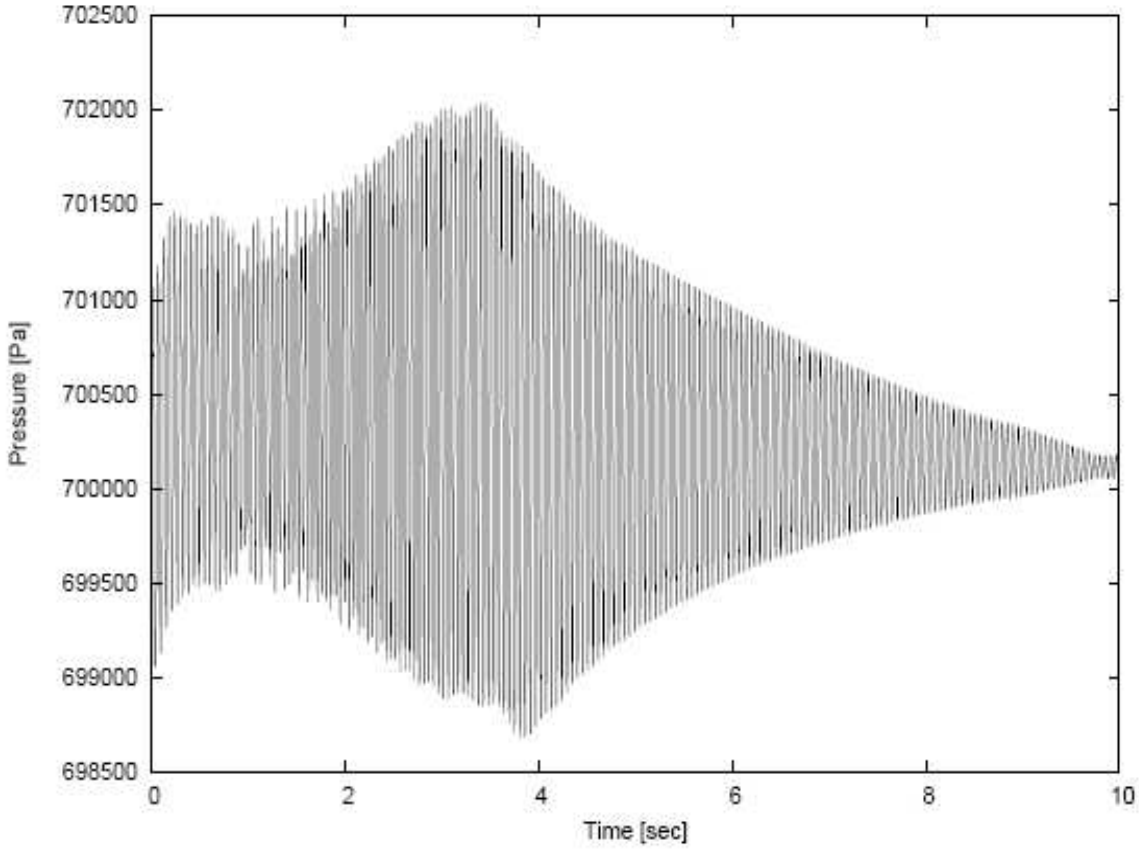


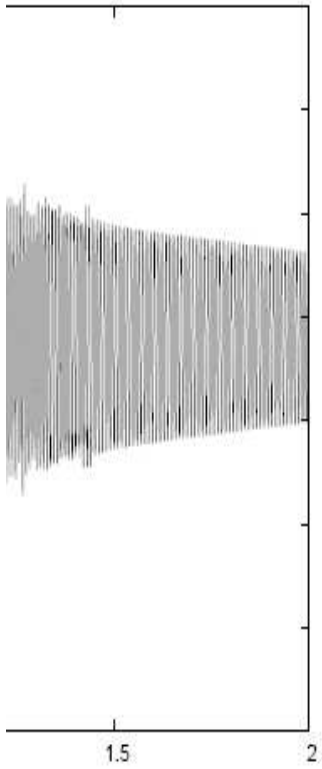
Large pressure peaks, probably too large

we plan measurements

The negative results







Pipe 2 and 3

Pipe 4

Summary and Outlook

we shortly presented the Budapest PMK-2 complex experimental facility

Gave a short/gentle introduction into a two-phase flow model

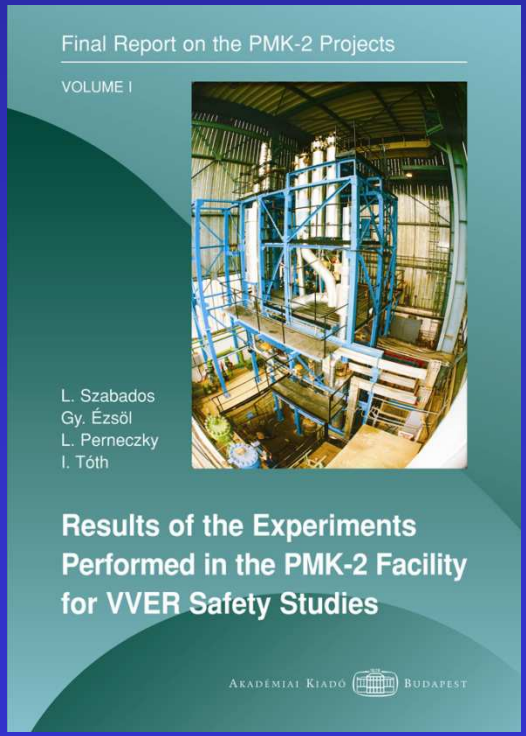
Presented former measurement and simulations ~ validation

Presented recent theoretical results for the NPP
Sufficient conditions are not enough, calcations are needed

The same modell is applied to calculate proton induced shock waves and cavitation in mercury, (Spallation Source ESS, JSNS)

There are liquid-metal (eq. Li) or liquid helium cooled systems as well… ☺
(work for the next 20-30 years)

Thank you for Your attention!



Questions, comments, remarks?...