A Suite of Methods Utilizing Tensioned Metastable Fluid Detectors for Active Cargo Interrogation to Interdict Special Nuclear Materials

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TMFD Methods for Active Interrogation of Cargo: An Overview

General System Improvements

⇒ ~~Design and cons~~truct "paddle" (50%)

⇒ ~~Design and construct~~ LW-MCTMFD (80%)

⇒ ~~Acoustically instrument CTMFDs~~ (60%)

⇒ ~~Multiplicity in CTMFD~~/ATMFD (25%)

⇒ Develop DFP EATMFD and PZT Filter

Threshold Energy Neutron Analysis (TENA)

⇒ ~~Proof of concept using CTMFDs for TENA~~

⇒ ~~Proof of concept using ATMFDs for TENA~~

⇒ ~~Optimization using density, meniscus,~~ and sensitivity compensation (90%)

⇒ ~~Characterization of S, M, L, C~~, CH (70%)

Photofission Cargo Interrogation

⇒ ~~Proof of concept for indirect γ exposure~~

⇒ Proof of concept for direct γ exposure

⇒ Proof of concept with source/detector shielding/collimation

⇒ Design rad-hardness into MCTMFD system

Differential Die Away Analysis (DDAA)

⇒ ~~Proof of concept with pulsed DT and DATMFD~~ (25%)

⇒ Proof of concept with pulsed DT and EATMFD

⇒ Temporal simulation for pileup, transient pressure field, and multiplicity

Acoustic Instrumentation of CTMFDs: Motivation and Concept

Motivation

$\Rightarrow$ Cavitation detection time uncertainty is driven by vapor column creation time

$\Rightarrow$ Cavitation detection time uncertainty currently is too high for quick resolution of multiplicity

$\Rightarrow$ Piezoelectric means may be preferable when in intense γ environments

Methodology

$\Rightarrow$ Piezoelectric device(s) attached to CTMFD bulb provide evidence of shock traces

$\Rightarrow$ Filter removes electronic noise and drive frequency

$\Rightarrow$ High speed ADC system detects rise in PZT signal

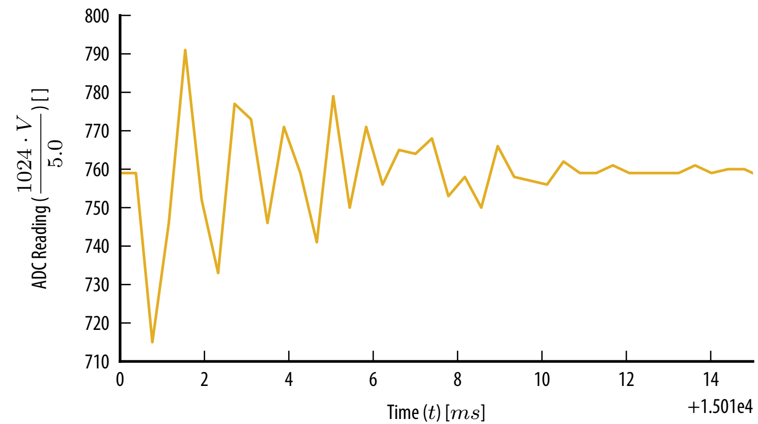

Figure 1: Shock trace using 3 kSps data rate

Acoustic Instrumentation of CTMFDs: System Concepts

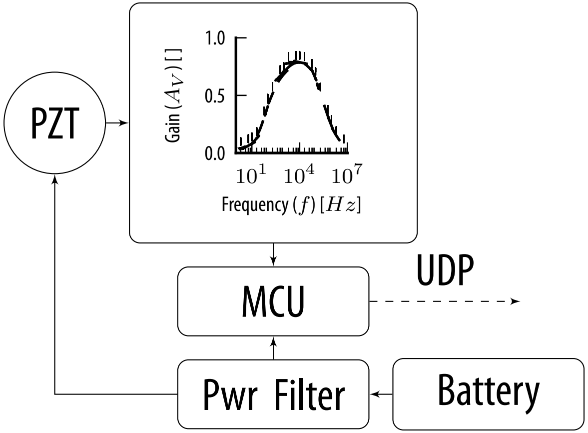

Figure 2: Flowchart of integrated system concept

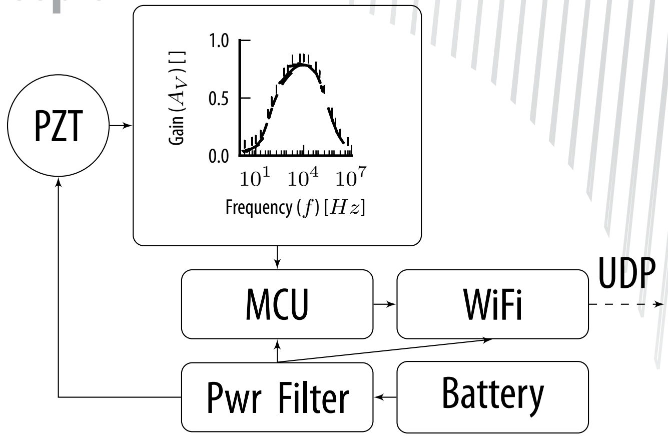

Figure 3: Flowchart of fast system concept

Beaglebone MCU - Integrated system

$\Rightarrow$ $f_{data} = 200$ kSps, $T_{data} = 5\ \mu$s

$\Rightarrow$ $t_{data\ frame}$ is continuous

$\Rightarrow$ Requirements: 1 MCU, 1 battery, 1 power board, 1 filter

Tiva C Delphino MCU - Fast system

$\Rightarrow$ $f_{data} => 1$ MSps, $T_{data} = 1\ \mu$s

$\Rightarrow$ $t_{data\ frame} = 45$ ms (45 kS)

$\Rightarrow$ Requirements: 1 MCU, 1 wireless connection board, 1 battery, 1 power board, 1 filter

Acoustic Instrumentation of CTMFDs: Achievements

What have we actually done?

$\Rightarrow$ Beaglebone MCU taking data at 200 kSps and continuously sending to computer over WiFi

$\Rightarrow$ Delphino MCU taking data at 1 MSps and sending to computer over USB (Tony)

$\Rightarrow$ Filter created with acceptable envelope

$\Rightarrow$ Power input filter created for BB MCU

$\Rightarrow$ Detection event comparisons using Bertholet tube (Tony)

What do we still need to do?

$\Rightarrow$ Integrate BB MCU with power input filter, pzt input filter, and battery

$\Rightarrow$ Design and 3d print "harness" for Integrated system on board

$\Rightarrow$ Test BB MCU on LCTMFD

$\Rightarrow$ Program Delphino MCU to send data to a WiFi Board

$\ldots$

Paddle C/CH-CTMFD System: Motivation and Concept

Motivation

$\Rightarrow$ Achievement of $2.5\ ^{cps}/_{\text{ng}}$

$\Rightarrow$ Competition against "Paddle" from Symmetrica (R)

Methodology

$\Rightarrow$ Five 65 cc/100 cc "C"/"CH"-CTMFDs

$\Rightarrow$ Stacked with cap closure - hose across for continuous pressure

$\Rightarrow$ DC motor able to spin to 60 rps (10 bar)

$\Rightarrow$ Triple bearing assembly for alignment

$\Rightarrow$ Precision Balancing Inc. for balancing

$\Rightarrow$ XBee or BB MCU for data transmission

Paddle C/CH-CTMFD System: Accomplishments

- ⇒ Machining out to machine shop
- ⇒ Glassblowing out to Superior Scientific Glass
- ⇒ Power supply identified (48 V, 10 A) - to be purchased
- ⇒ Instrumentation possible through BB MCU or XBee
- ⇒ Estimated delivery 3 - 5 weeks

Figure 4: Design of Column C-CTMFD Revision 0

Lightweighting of M-CTMFD: Status of the Project

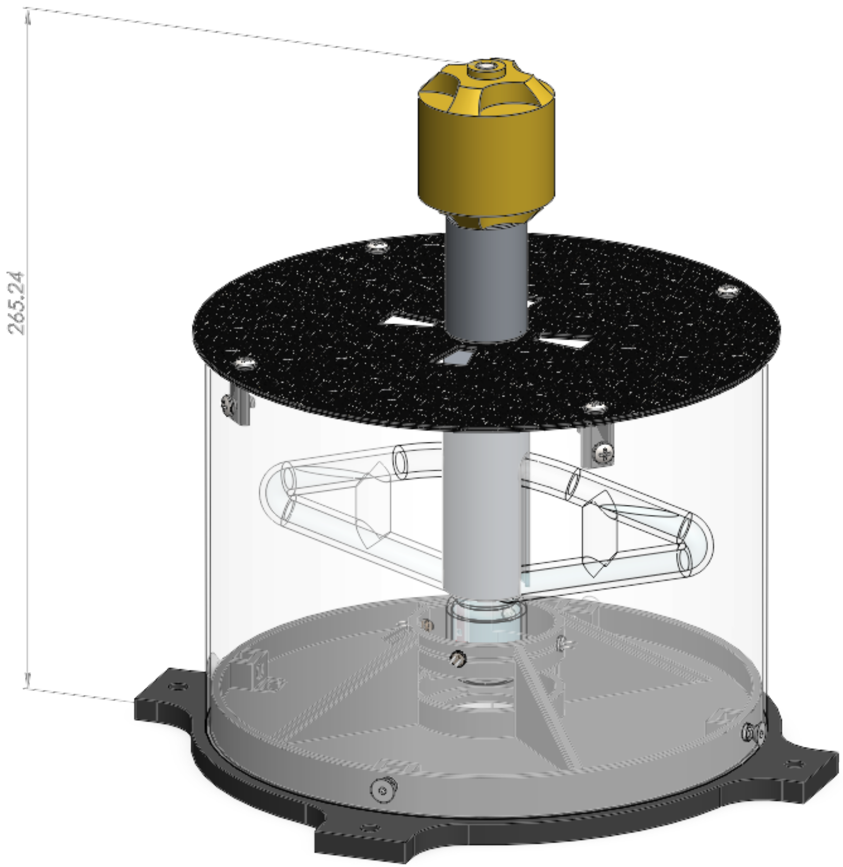

Figure 5: Design of Lightweight M-CTMFD Revision 2

- $\Rightarrow$ Continuous current needed measured (< 3 A for 4 bar)
- $\Rightarrow$ Power supply purchased - able to run 2 systems (Brian)
- $\Rightarrow$ Plate, Bearing and shaft out to machine shop
- $\Rightarrow$ Shortened base received this week
- $\Rightarrow$ Estimated delivery 1 - 2 weeks

Threshold Energy Neutron Analysis: Concept

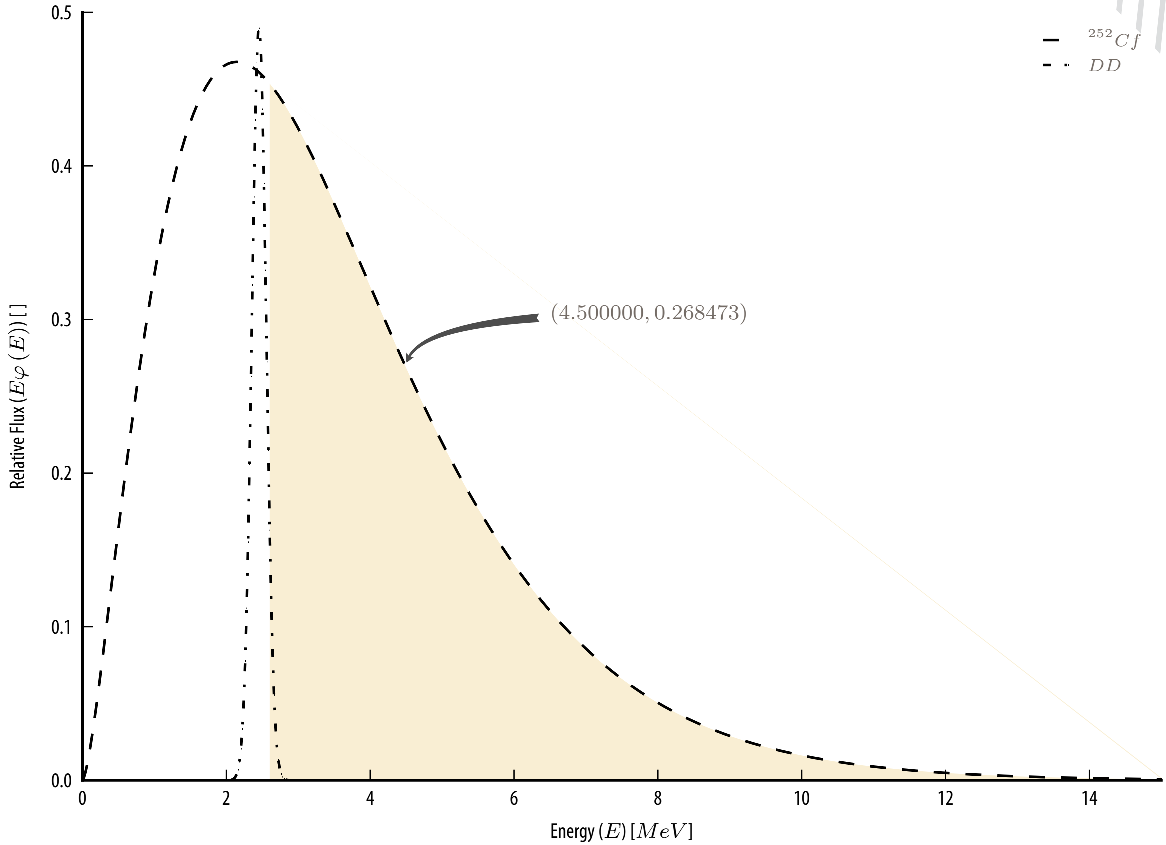

Figure 6: Threshold Energy Fission Discrimination

Threshold Energy Neutron Analysis: Accomplishments

Table 1: Accomplishments with different TMFD Detectors at using TENA to discriminate fission neutrons

Name	Sensitive Volume	No Temperature Compensation r_η	Density/Meniscus Compensated r_η	Full Compensation r_η
M(s)-CTMFD	3 cc	17		
M-CTMFD	15 cc	132	$< 1.7 \times 10^4$	Planned for 3/16
L-CTMFD	40 cc	$> 1 \times 10^4$	$< 2.5 \times 10^4$	Planned for 4/16
C-CTMFD	65 cc	538	Planned for 3/16	Planned for 4/16
CH-CTMFD	100 cc	-	Planned for 3/16	Planned for 4/16
EATMFD Acetone	170 cc	< 1		
TEATMFD DFP	~ 200 cc	Planned for 9/16		
DATMFD Acetone	35 cc	Planned for 9/16		

Threshold Energy Neutron Analysis: Temperature Compensation (1/2)

- $\Rightarrow$ Currently adjust density using correlation shown at right
- $\Rightarrow$ Adjust meniscus using experimental values for meniscus at different temperatures (linear)
- $\Rightarrow$ Apparent "plateau" of threshold pressure at > 25°C

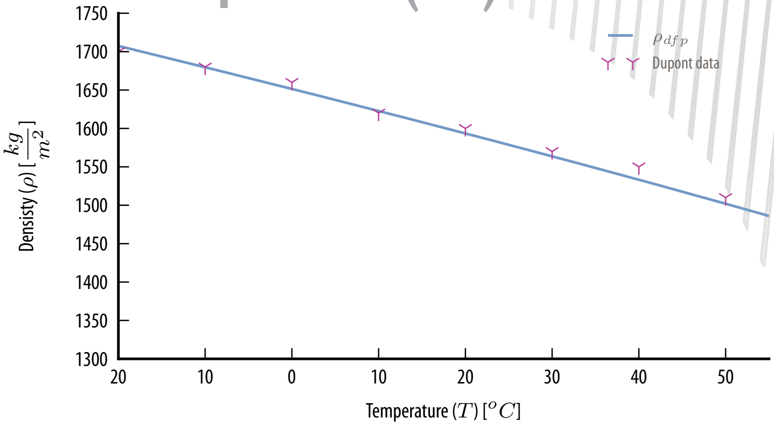

Figure 7: Currently used density correlation to adjust density and meniscus

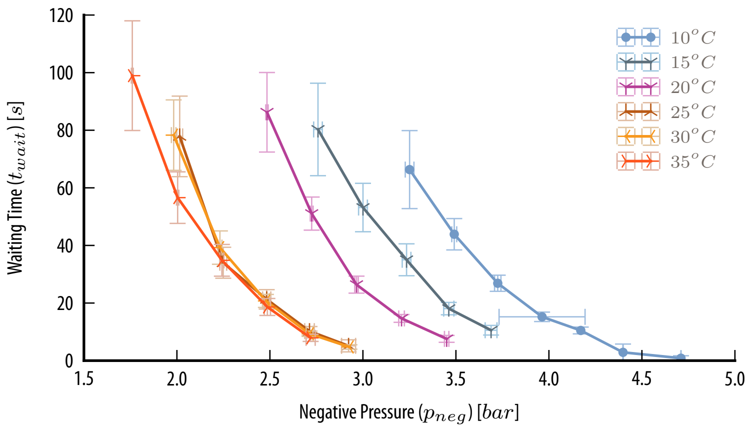

Figure 8: Analysis of waiting times at varying temperatures

Threshold Energy Neutron Analysis: Temperature Compensation (2/2)

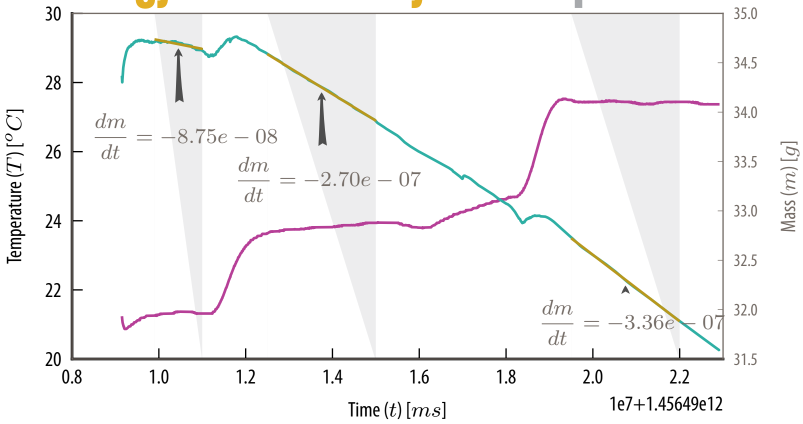

Figure 9: Evaporation rate of DFP with different constant temperatures

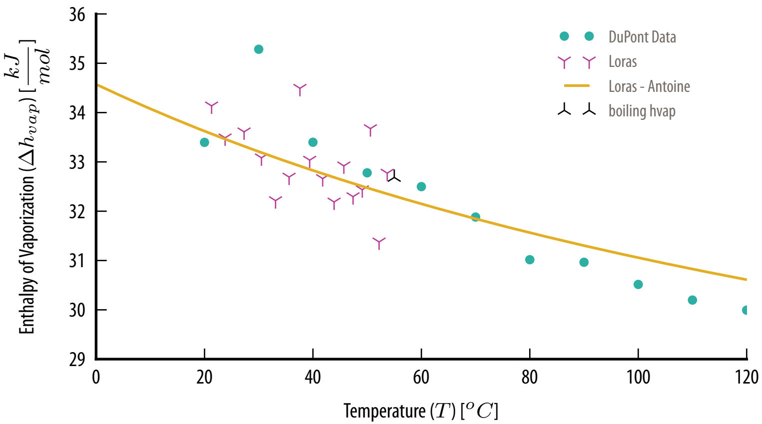

Figure 10: Calculated Δh_{vap} from Claussius-Clapyron equation and experimental or Antoine values for boiling temperature and vapor pressure

- $\Rightarrow$ Δh_{vap} correlations from several sources shown to left
- $\Rightarrow$ No large change in values around 25^oC
- $\Rightarrow$ Other parameter must be the reason for threshold “plateau”

Threshold Energy Neutron Analysis: Proposed Plan (2/16 - 5/16)

$\Rightarrow$ Determine threshold pressure at 22^{o}C

$\Rightarrow$ Adjust data for average instead of centerline negative pressure

$\Rightarrow$ Develop $p_{neg,\ stp\ equivalent}$ relation

$\Rightarrow$ Validate TENA with this in M-CTMFD

$\Rightarrow$ Continue to characterize C-, CH- CTMFDs

Interdiction of SNM with photofission:

- $\Rightarrow$ TMFDs are γ blind
- $\Rightarrow$ Much γ interrogation infrastructure is already in place
- $\Rightarrow$ Suffers background from ^{2}H and ^{13}C

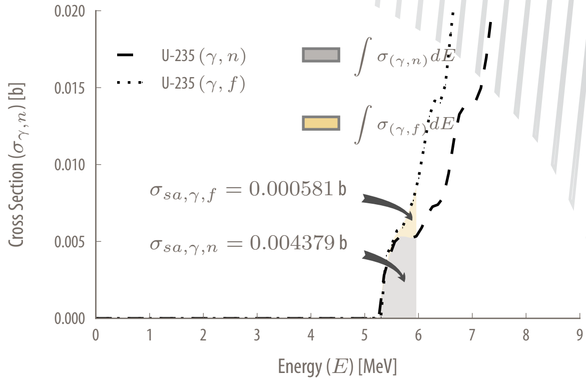

Figure 11: Uranium (γ, n) and (γ, f) cross sections at < 7 MeV

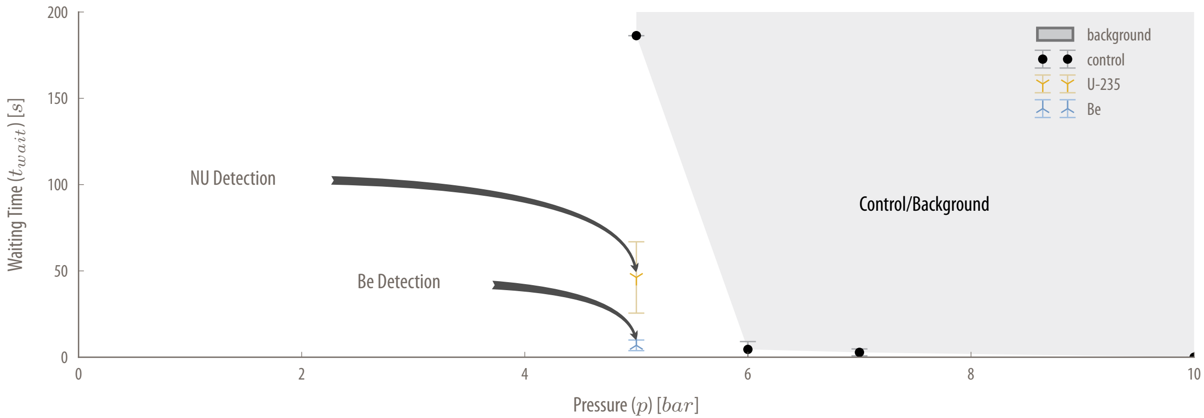

Figure 12: Results from preliminary test with CLINAC

Interdiction of SNM with photofission: Proposed Plan (5/16 - 7/16)

$\Rightarrow$ Return to CLINAC for experiment (5/16 - 6/16) with

- $\rightarrow$ PFO
- $\rightarrow$ PFPE
- $\rightarrow$ Floor shielding
- $\rightarrow$ Detector shielding
- $\rightarrow$ Use of broken fission detector for HEU source

$\Rightarrow$ Perform MCNP6 assessments of photoneutron production rates in ANSI standard cargo

Differential Die Away Analysis: Introduction

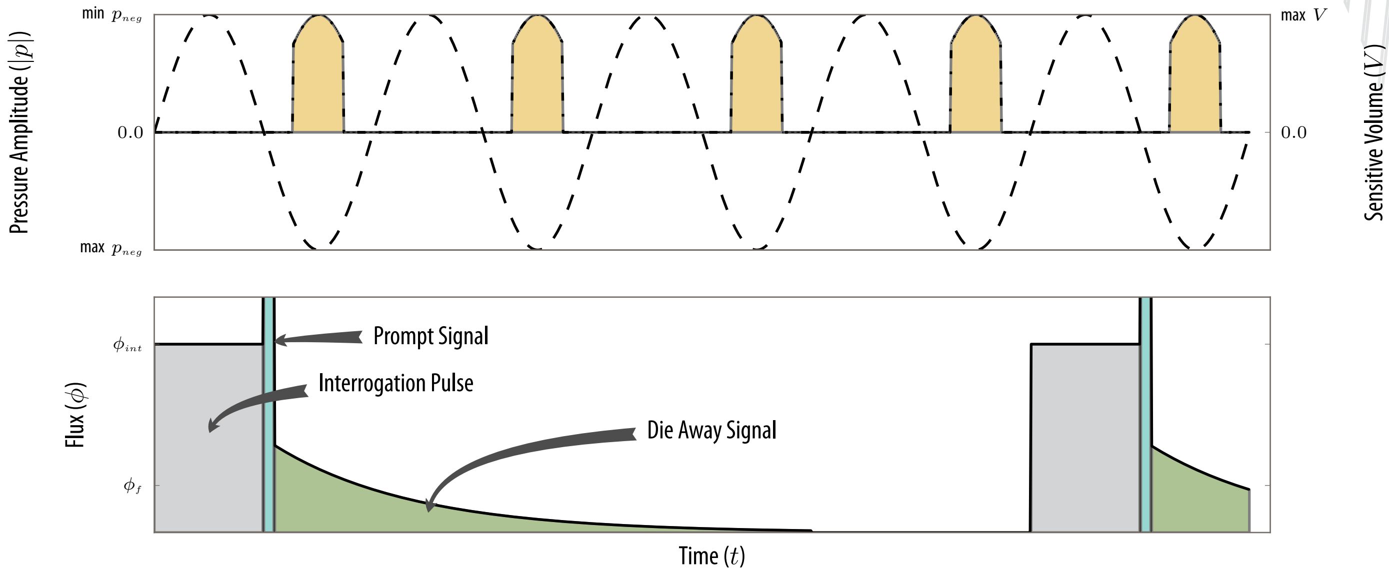

Figure 13: Differential die away analysis schematic

Differential Die Away Analysis: Proposed Plan (10/16 - ...)

⇒ Develop TEATMFD for use with DFP

⇒ Develop filter for “directionality” in TEATMFD with DFP

⇒ Perform temporal pressure analysis in TEATMFD with COMSOL

⇒ Pulse DT generator while TEATMFD is sensitive

⇒ Run DD generator contiuously while TEATMFD is sensitive and time-veto cavitations after detection