

Diehl & Eagle Picher Contact

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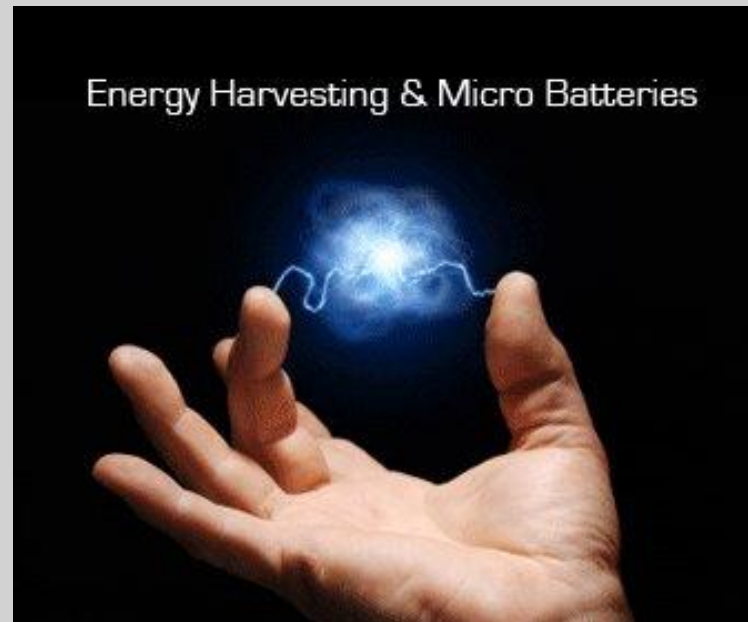
Mid Range Fuze Power - Energy Harvesting/Batteries/or?



56th Fuze Conference
May 16th, 2012, Baltimore, MD
Harald Wich

Outline

- ◆ Recapitulation
- ◆ Energy Provisioning
- ◆ Munitions unique Energy Sources
- ◆ TE – Conversion
- ◆ Test Setup
- ◆ TEG Energy Source



& more?

Recapitulation

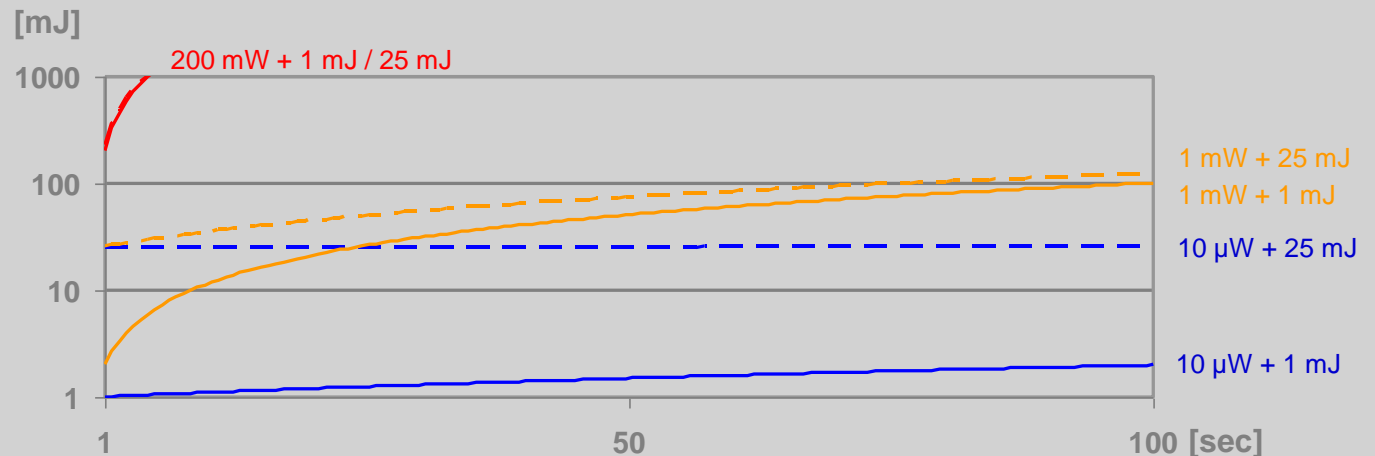
- ◆ Fuze Categories
 - PD Det
 - SD Det + Timer
 - ET Det + programmable Timer
 - PX Det + prog. Timer + TX/RX
 - CCF Det + prog. Timer + TX/RX + Control Power
- ◆ Operating Times
 - short $\leq 10 - 20$ sec direct fire
 - medium < 100 sec indirect fire Mortars

Recapitulation

		<i>M100 / SBI</i>
◆ Fuze Categories	PD	1 mJ / 25 mJ
	SD	(1 mJ / 25 mJ) + 0.01 x t mJ
	ET	(1 mJ / 25 mJ) + 1 x t mJ
	PX	(1 mJ / 25 mJ) + 1 x t ₁ + 200 x t ₂ mJ
	CCF	Det + prog. Timer + TX/RX + Control Power

◆ Operating Times	short	≤ 10 – 20 sec	direct fire
	medium	< 100 sec	indirect fire Mortars

◆ Energy

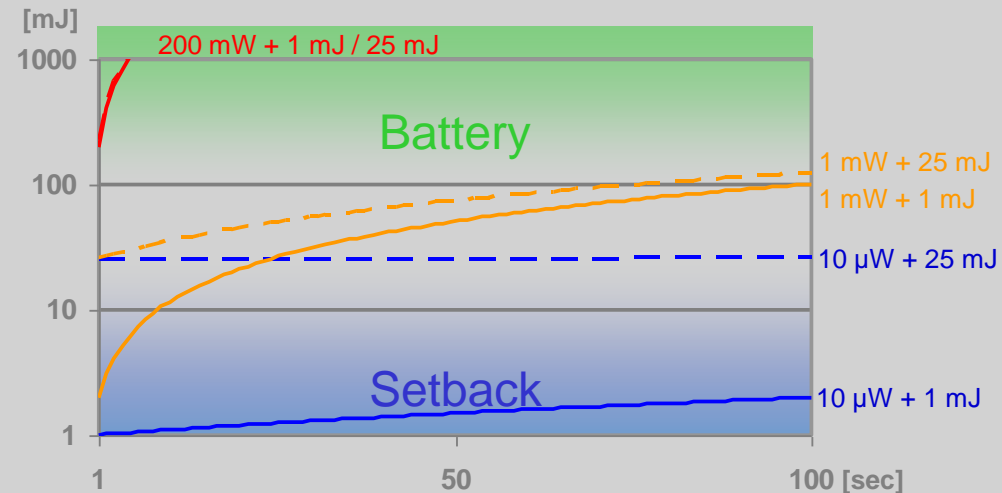


Energy Requirement for Medium Calibre ranges from 1 ÷ 100 mJ's

How is the Fuze Energy provide

◆ A wide range of Energy levels

- less than 10 mJ's;
well covered by a plethora of **Setback Generators**
- above 1 J;
well covered by **Reserve Batteries** and EM-Air Turbines



⇒ mid range – defined here as 10 mJ ÷ 1,000 mJ – is somewhat diverse


◆ Why is that?

- Batteries and Turbines can certainly cover the Energy range required however, it is difficult to get them small enough
- Setback Generators grow rapidly in size if higher Energy Output is required

Energy Density is the Keyword

Energy Density

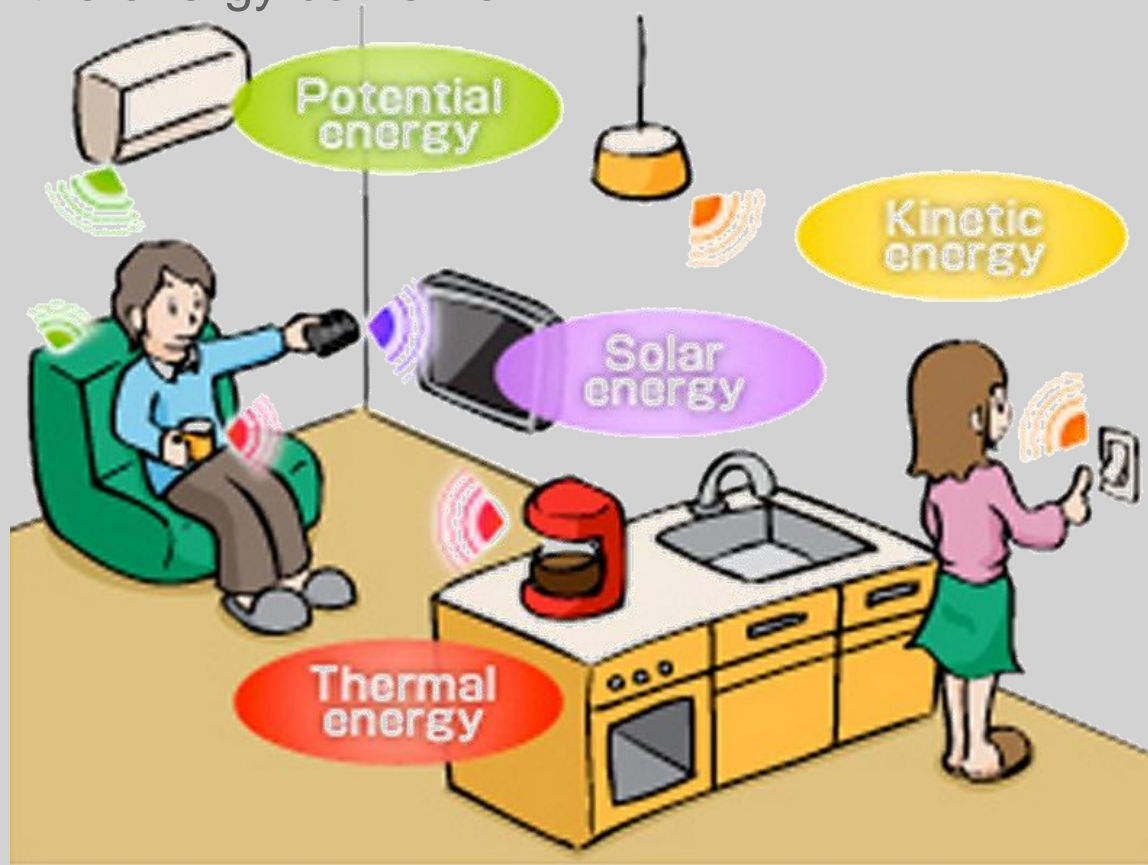
- ◆ As a reminder from last years presentation:
 - Energy density for Setback Generators has **not exceeded 5 $\mu\text{J}/\text{mm}^3$** (neither EM- nor Piezo-Type) over the last 70 years!
- ◆ Whereas requirements of
 - 60 $\mu\text{J}/\text{mm}^3$; 30 mJ total, (industrial customer)
 - 40 $\mu\text{J}/\text{mm}^3$; 60 mJ total, (US SBIR A09-032 [Army])
 do exist!

example	requirement	10 mJ	100 mJ	1,000 mJ	10 J
EM-, PZ- setback generator		2,000 mm^3  12.6 mm	20,000 mm^3  27.1 mm	200,000 mm^3  58.5 mm	
12 x 12 TLC reserve battery		1 mm^3  1 mm	10 mm^3  2.2 mm	100 mm^3  4.6 mm	1,000 mm^3  10 mm

An Alternate System should/must cover 10 mJ \div 1,000 mJ

Energy Sources

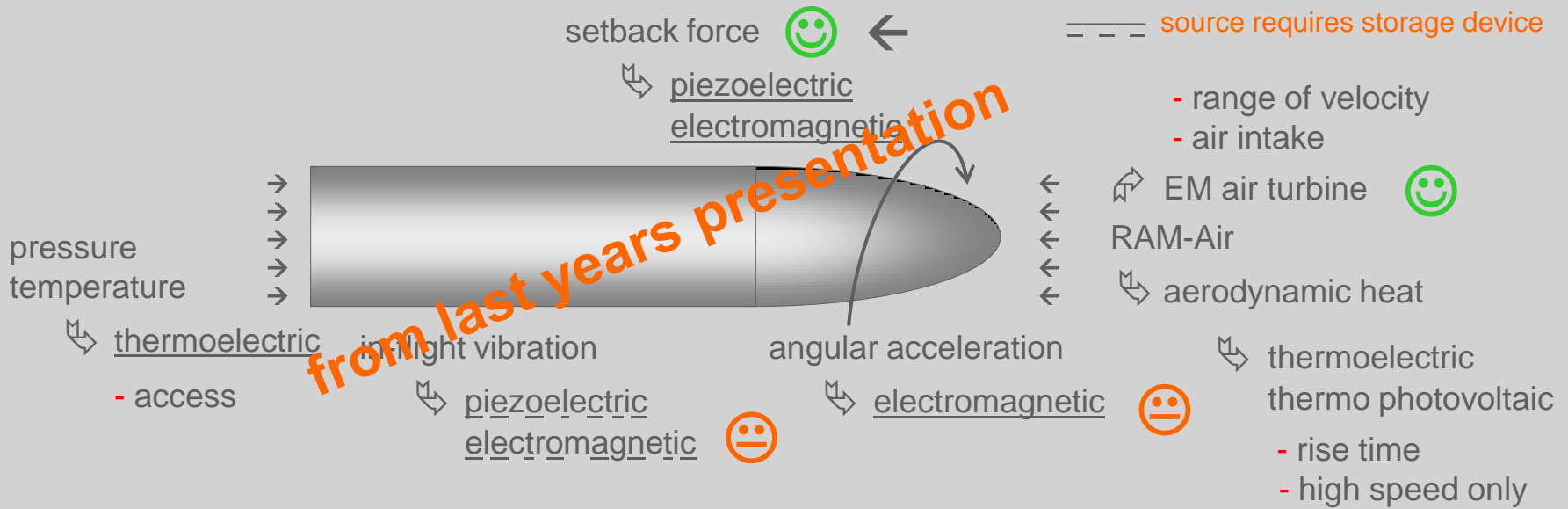
- ◆ Where could the energy come from



Using energy sources all around us to power everyday electronic devices!

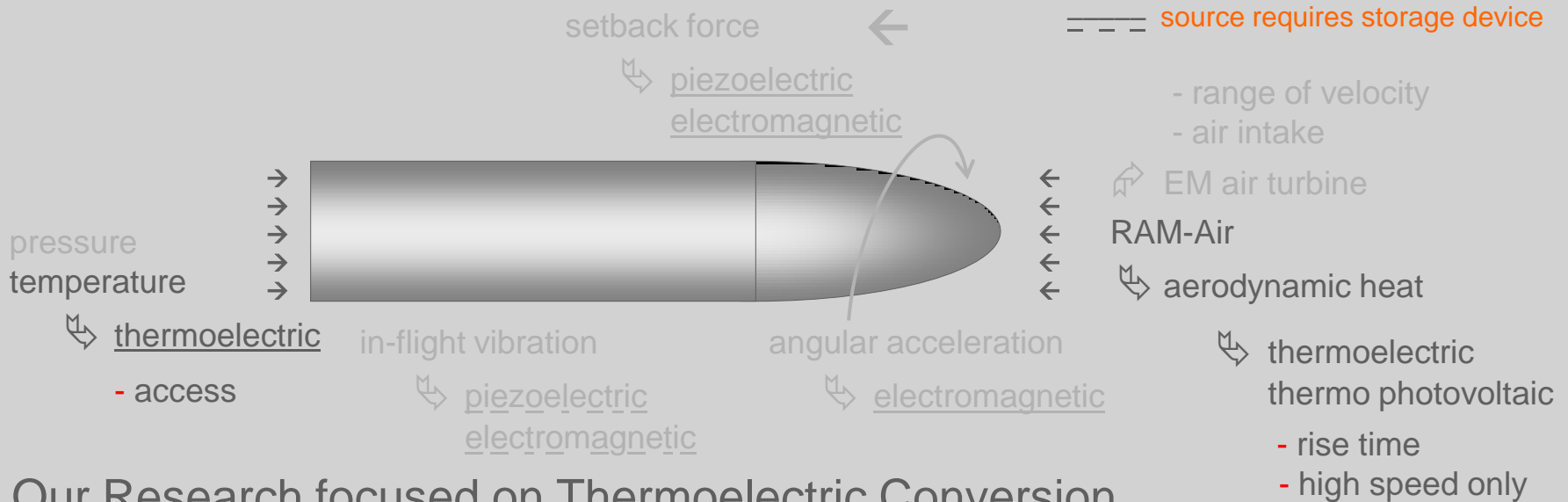
Energy Sources

- Where could the energy come from

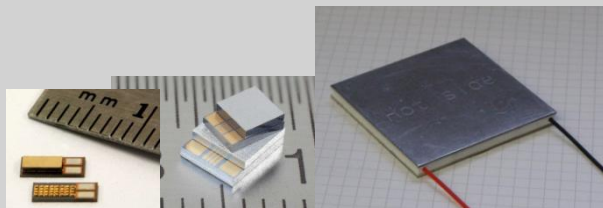


Energy Sources

◆ Where could the energy come from



◆ Our Research focused on Thermoelectric Conversion



low T_{max} high U_{TEG}



high T_{max} medium U_{TEG}



very high T_{max} low U_{TEG}

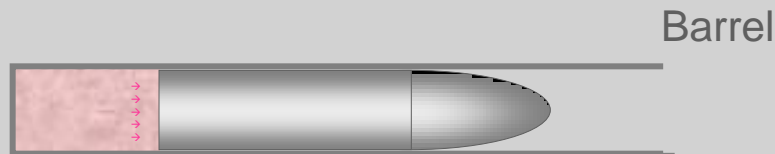
Harvesting from a Temperature-(difference)

- ◆ As a conservative approach lets assume

to generate	100	1,000 mJ	<i>electrical output</i>
requires	10	100 J	$\eta = 1\%$
	100	1,000 J	$\eta = 0.1\%$
			<i>thermal input!</i>

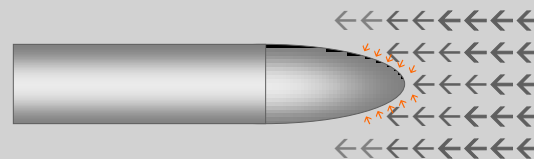
- ◆ Two options to harvest thermal energy in a projectile

Projectile Base



- heat transfer during barrel transit
- high temperature, very short duration

Projectile Nose



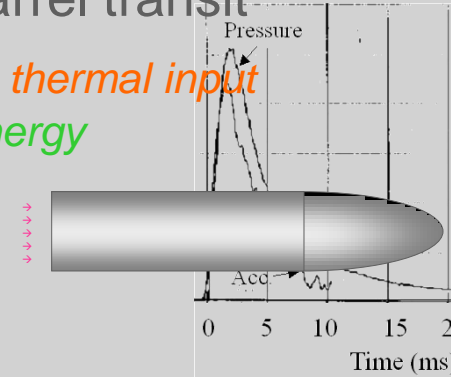
- heat transfer during free flight
- low temperature, delayed response

Harvesting from a Temperature-(difference)

- ♦ Is a projectile base able to harvest $10 \div 1,000$ J during barrel transit

e.g. 40 mm IG HV interaction time < 15 msec $\Rightarrow 1 \div 100$ kW *thermal input*
 projectile total energy ≈ 10 kJ *kinetic energy*

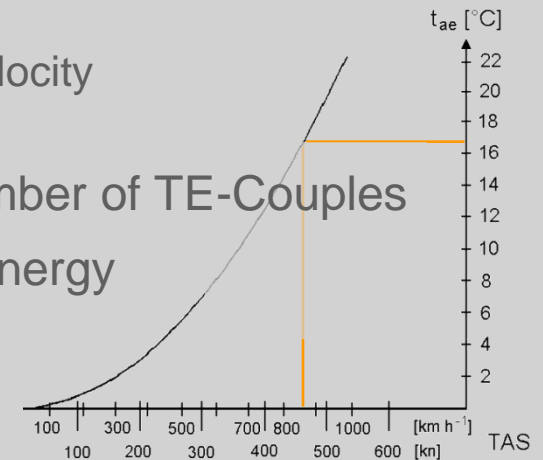
- Fast energy transfer from hot gases to heat sink as well as structural requirements prevents good thermal insulation



- ♦ Can a projectile nose harvest $10 \div 1,000$ J in flight

e.g. 40 mm IG HV projectile velocity $v_0 \approx 240$ m/sec
 rather low $\Delta\vartheta \approx 16$ °C for max velocity

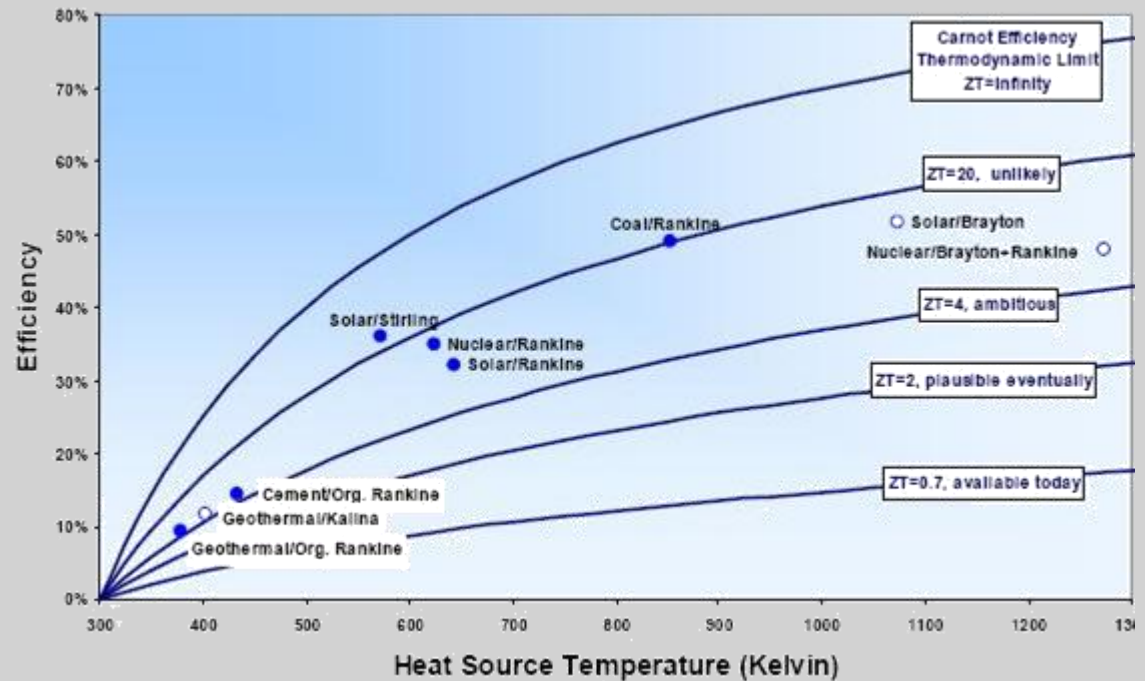
- Low $\Delta\vartheta$ requires high Seebeck coefficient or/and number of TE-Couples
- Temperature rise time delays availability of electric energy



Is this the End of our Story?

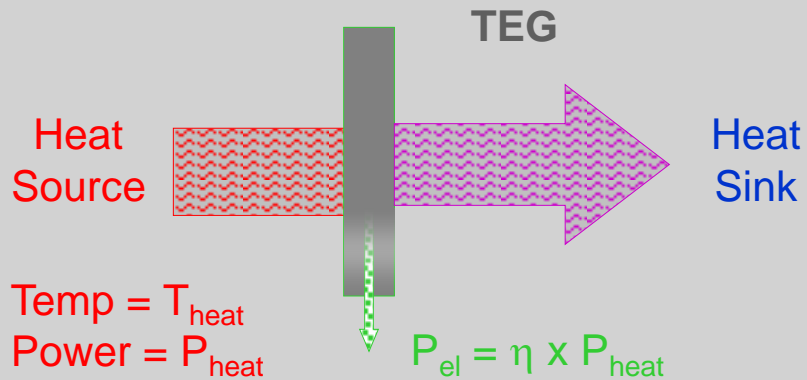
TE Energy Conversion

- ◆ Thermoelectric conversion – notoriously – suffers from very low efficiency



TE Energy Conversion

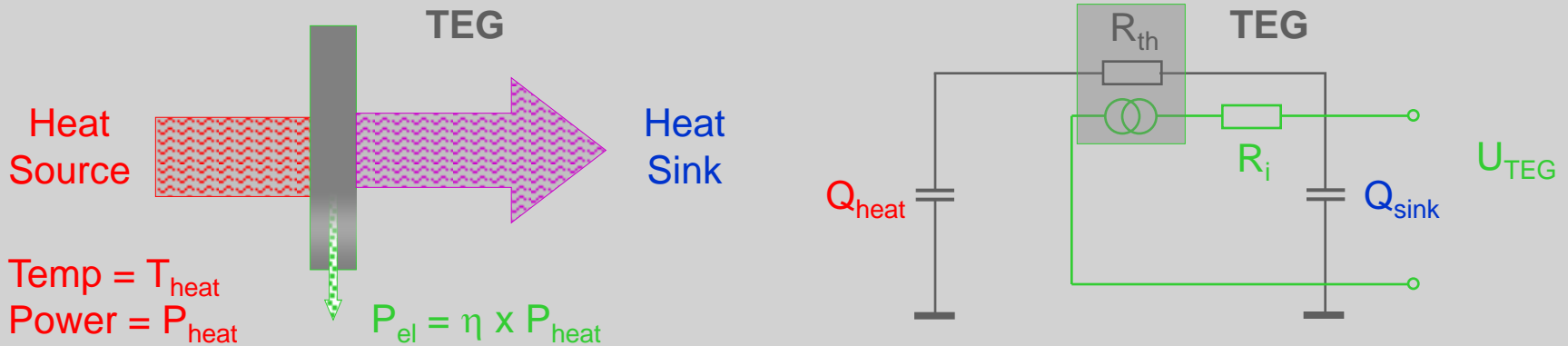
- ◆ Thermoelectric conversion – notoriously – suffers from very low efficiency



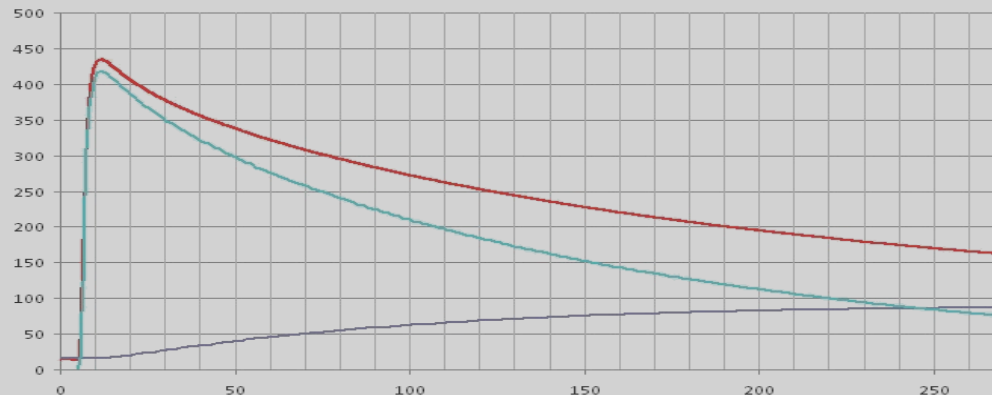
TE Conversion requires very high Energy Heat Source

TE Energy Conversion

- ◆ Thermoelectric conversion – notoriously – suffers from very low efficiency



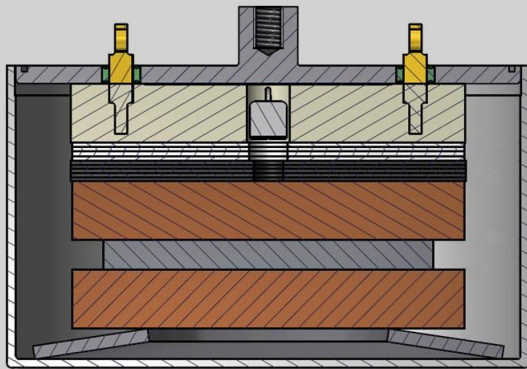
- ◆ TE energy conversion requires heat source and sink capacities



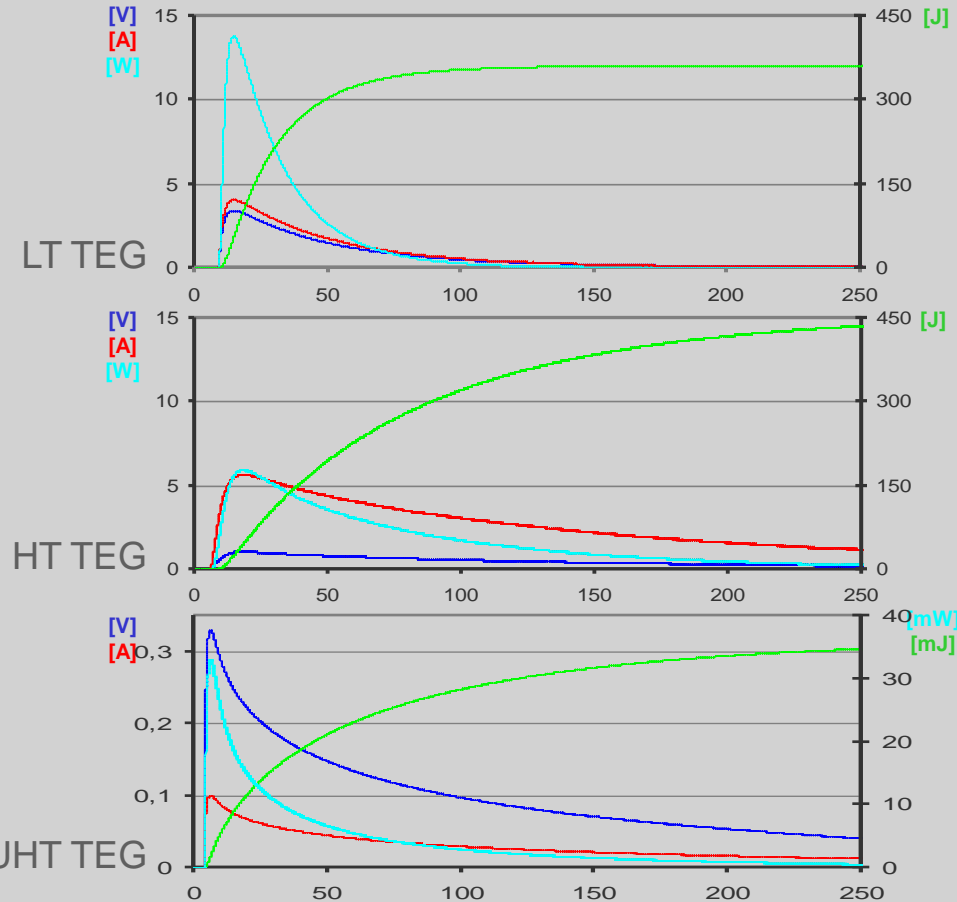
- ◆ High power at start
- ◆ Long lifetime with high R_{th} and good thermal insulation

Thermoelectric Test Setup

- ♦ Evaluation of the principle with internal heat source



Heat
Hot Buffer
TEG
Cold Buffer



TEG with internal Heat source looks feasible

TEG with internal Heat

- ◆ How to provide the internal heat energy

- as an example Fe/KClO₄

to generate	100 mJ	1,000 mJ	<i>electrical output</i>
requires	2.5 mm ³	25 mm ³	$\eta_{\text{tot}} = 1\%$
	25 mm ³	250 mm ³	$\eta_{\text{tot}} = 0.1\%$

heat powder !

this equals a 3 mm cube

- ◆ Compact heat source is feasible

- Even 1,000 J heat capacity is less than ¼-inch cube

- ◆ Micro size TEG's are available off-the-shelf

- ◆ Miniaturisation of activation system will be the future challenge



100 $\mu\text{J}/\text{mm}^3$ will already be reached with existing Activation

TEG Energy Source Perspective

- ◆ TEG-Power Sources with internal Heat are very feasible for mid range Energy Requirements $10 \div 1,000$ mJ
 - very robust design (no liquids, glass ampoules, etc.)
 - no spin required for activation
 - works under high spin environment
 - very long storage live
 - no corrosive electrolyte
 - hermetically sealed
 - no toxic materials
 - high peak power on start
 - energy density to be estimated $\geq 500 \mu\text{J}/\text{mm}^3$ (100 x setback generators density)



TEG's with internal Heat Source can cover mid range Power Requirements

Thank you for your Attention!

Any Questions, Comments, Objections, ...

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Diehl & Eagle Picher in a Nutshell

- ◆ About the company
 - US/German Joint Venture; Shareholders are Eagle Picher Technology, Joplin MO and Diehl BGT Defence, Ueberlingen GE
 - Located in Roethenbach Germany
 - Thermal- and Fuze-Batteries and Battery Packs
 - R&D and Production of the above Batteries and Energy Sources of all kind for Fuzes, Munitions and Missiles
 - Annual Turn Over > 10 mEur

Small Liquid Reserve Battery

- ◆ For small and medium calibre applications



- 12 mm diameter
- 12 mm high
- single cell Lithium Battery
- 3.0 ÷ 3.6 V closed circuit voltage
- up to 50 mA load current
- setback/spin activation mechanism
 - > 7000 g activation
 - fast - < 5 ms - activation under spin environment
- lifetime > 50 s
- wide temperature range -46°C to +63 C
- very long shelf life – up to 20 years
- reliable
- low cost

Lithium Liquid Reserve Batteries provide superior Energy Density