DIEHL & EAGLE PICHER
Batterie-Systeme

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

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

Outline

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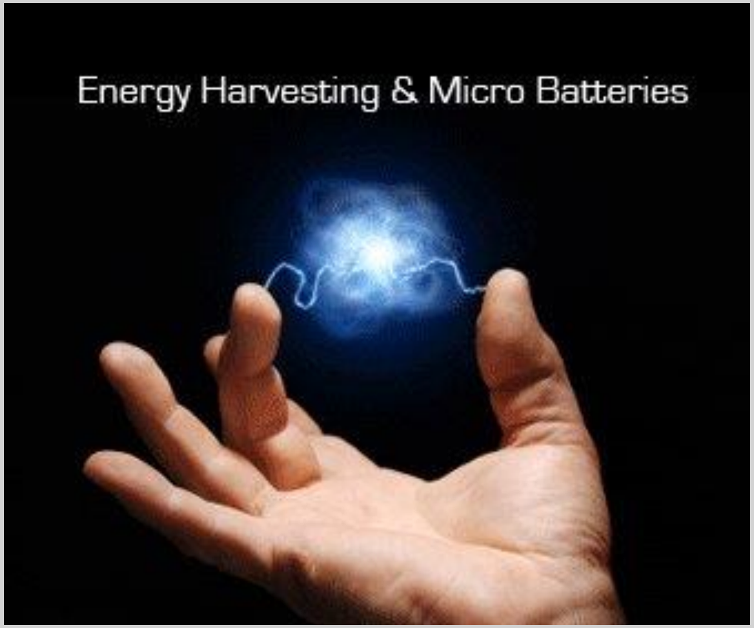
- Recapitulation
- Energy Provisioning
- Munitions unique Energy Sources
- TE – Conversion
- Test Setup
- TEG Energy Source



& 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	≤ 10 – 20 sec	direct fire
medium	< 100 sec	indirect fire Mortars

Recapitulation

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- Fuze Categories

	M100 / SBI
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

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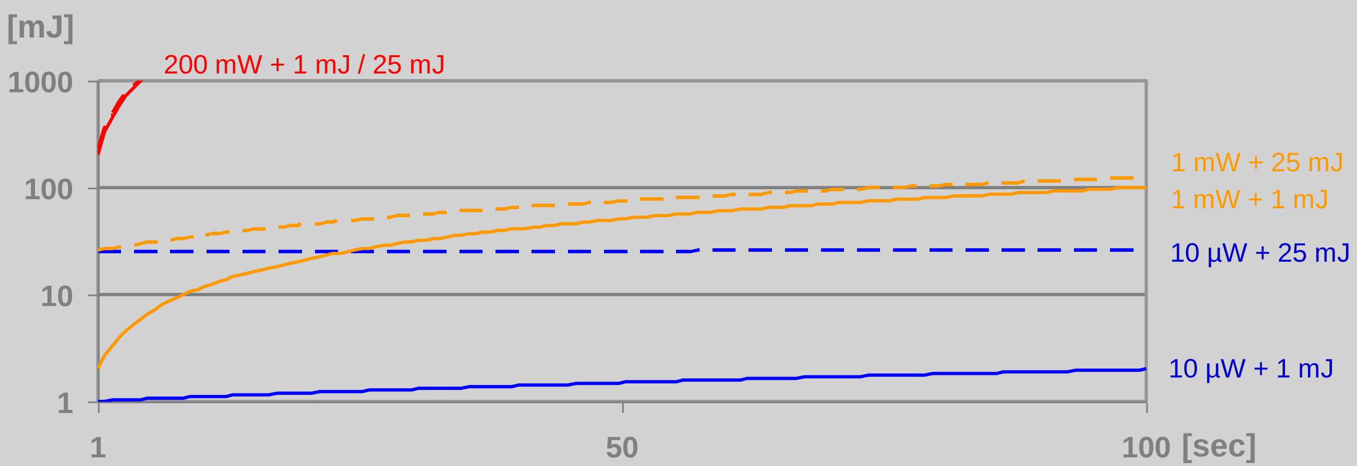
- Energy



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

How is the Fuze Energy provide

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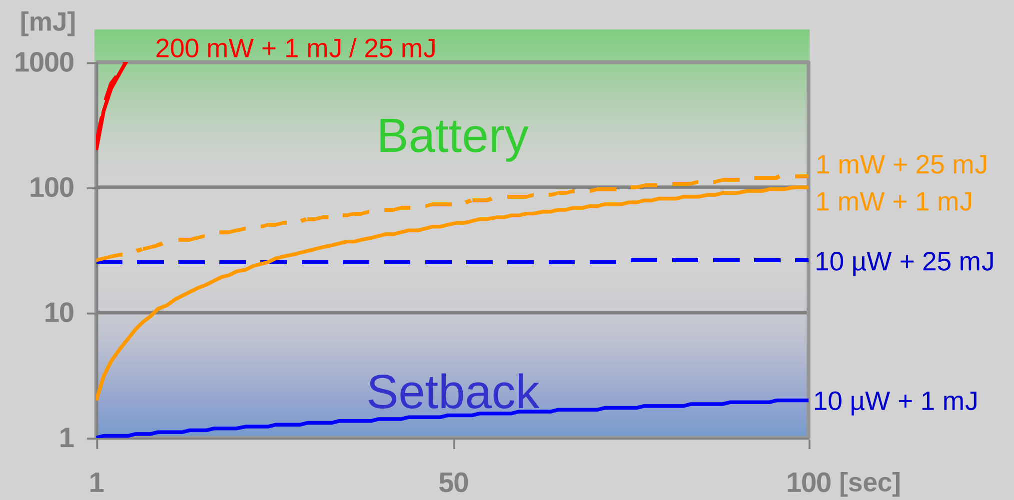
- A wide range of Energy levels
  - less than 10 mJ´s;
    well covered by a plethora of
    Setback Generators
  - above 1 J;
    well covered by
    Reserve Batteries and
    EM-Air Turbines



⇨ 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

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- As a reminder from last years presentation:
  - Energy density for Setback Generators has not exceeded 5 µJ/mm³ (neither EM- nor Piezo-Type) over the last 70 years!
- Whereas requirements of
  - 60 µJ/mm³; 30 mJ total, (industrial customer)
  - 40 µJ/mm³; 60 mJ total, (US SBIR A09-032 [Army])

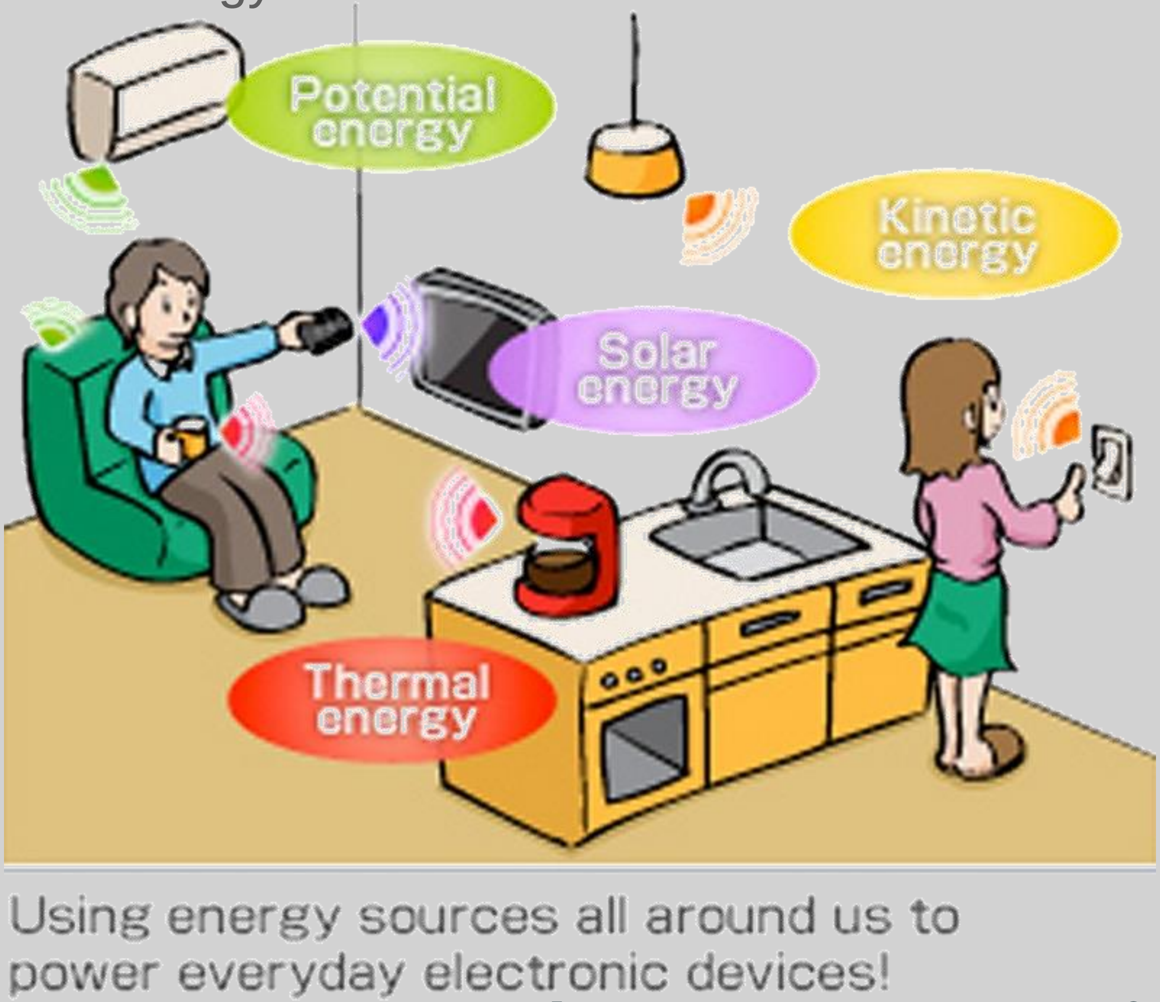
  do exist!

example	requirement	10 mJ	100 mJ	1,000 mJ	10 J
EM-, PZ- setback generator		2,000 mm³ 12.6 mm	20,000 mm³ 27.1 mm	200,000 mm³ 58.5 mm	
12 x 12 TLC reserve battery		1 mm³ 1 mm	10 mm³ 2.2 mm	100 mm³ 4.6 mm	1,000 mm³ 10 mm

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

Energy Sources

- Where could the energy come from



Energy Sources

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- Where could the energy come from

source requires storage device

setback force
piezoelectric
electromagnetic

- range of velocity
- air intake

pressure
temperature
thermoelectric
- access

from last years presentation

EM air turbine
RAM-Air
aerodynamic heat

in-flight vibration
piezoelectric
electromagnetic

angular acceleration
electromagnetic

thermoelectric
thermo photovoltaic
- rise time
- high speed only

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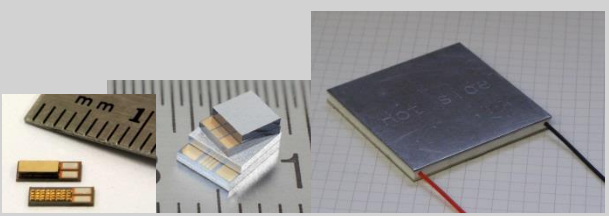
- Our Research focused on Thermoelectric Conversion



low T_{max} high U_{TEG}

high T_{max} medium U_{TEG}

very high T_{max} low U_{TEG}

Harvesting from a Temperature-(difference)

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- As a conservative approach lets assume

to generate	100	1,000 mJ	*electrical output*
requires	10	100 J	η = 1%
	100	1,000 J	η = 0.1%
			thermal input!

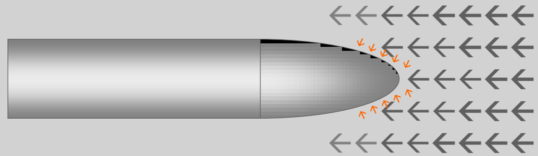
- Two options to harvest thermal energy in a projectile

Projectile Base

Barrel

- ➢ 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)

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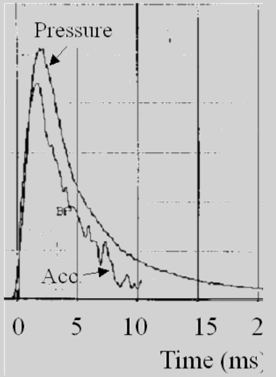
- Is a projectile base able to harvest 10 ÷ 1,000 J during barrel transit

e.g. 40 mm IG HV interaction time < 1.5 msec ⇨ 10 ÷ 1000 kW *thermal input*
projectile total energy ≈ 10 kJ *kinetic energy*



Harvesting from a Temperature-(difference)

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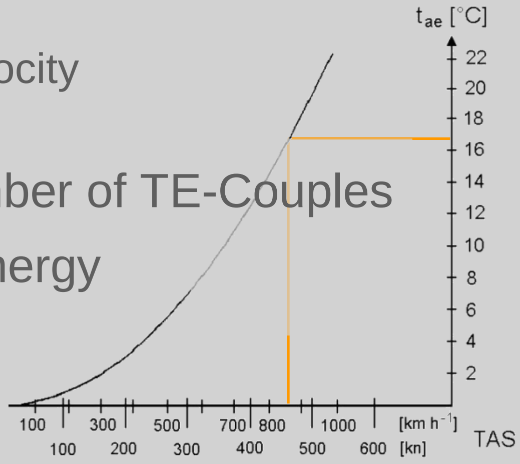
  e.g. 40 mm IG HV interaction time < 1.5 msec ⇨ 10 ÷ 1000 kW *thermal input*
  projectile total energy ≈ 10 kJ *kinetic energy*

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

- Can a projectile nose harvest 10 ÷ 1,000 J in flight

  e.g. 40 mm IG HV projectile velocity v_0 ≈ 240 m/sec
  rather low $\Delta\vartheta$ ≈ 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

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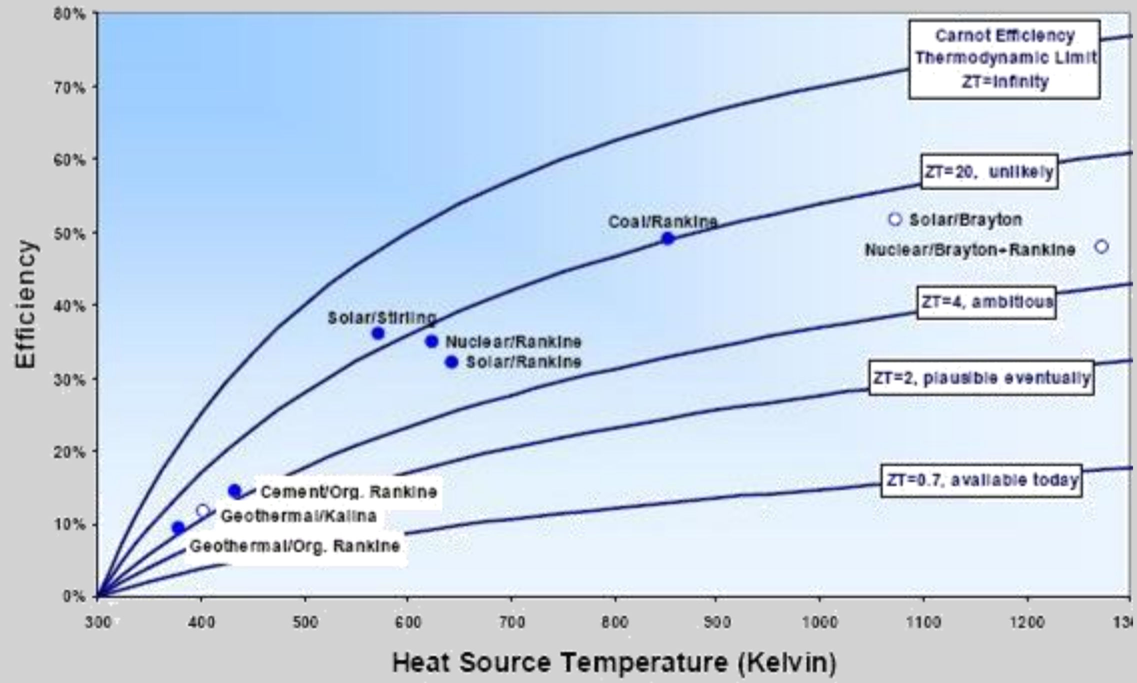
- Thermoelectric conversion – notoriously – suffers from very low efficiency



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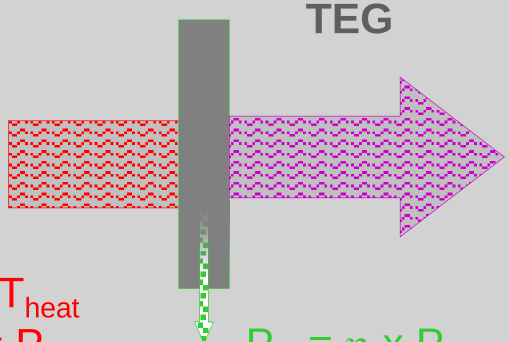

TE Conversion requires very high Energy Heat Source

TE Energy Conversion

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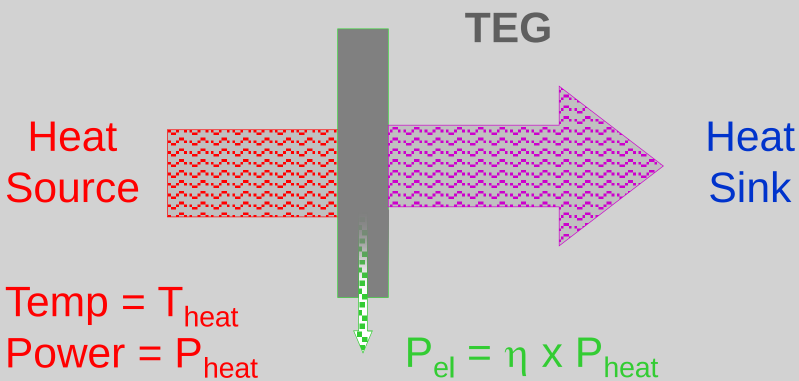
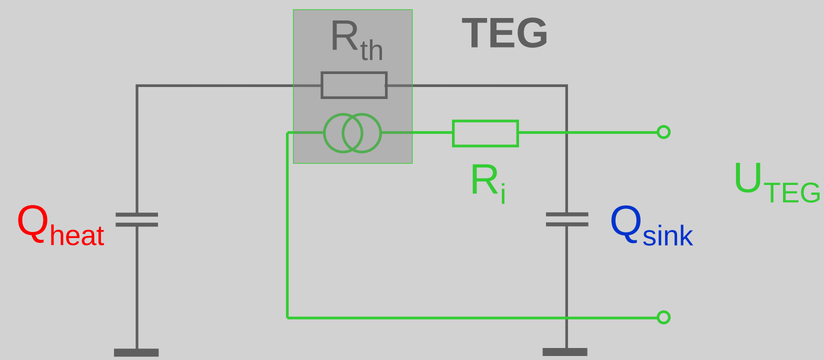
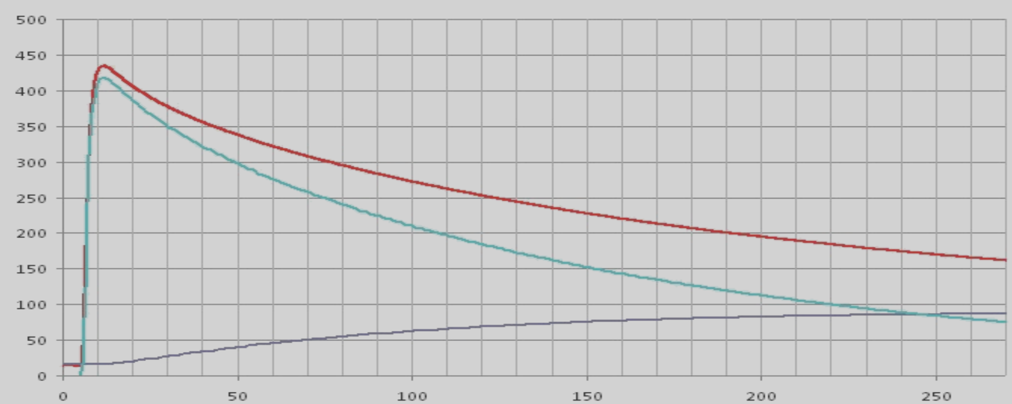




- TE energy conversion requires heat source and sink capacities



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

Thermoelectric Test Setup

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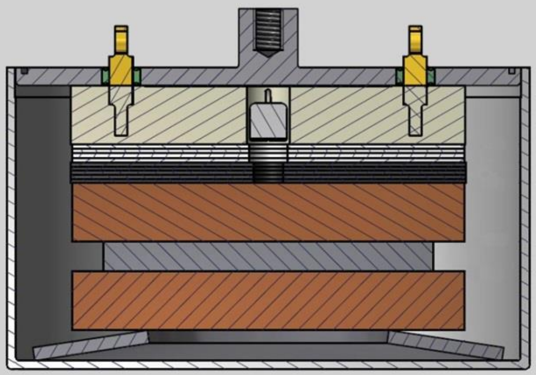
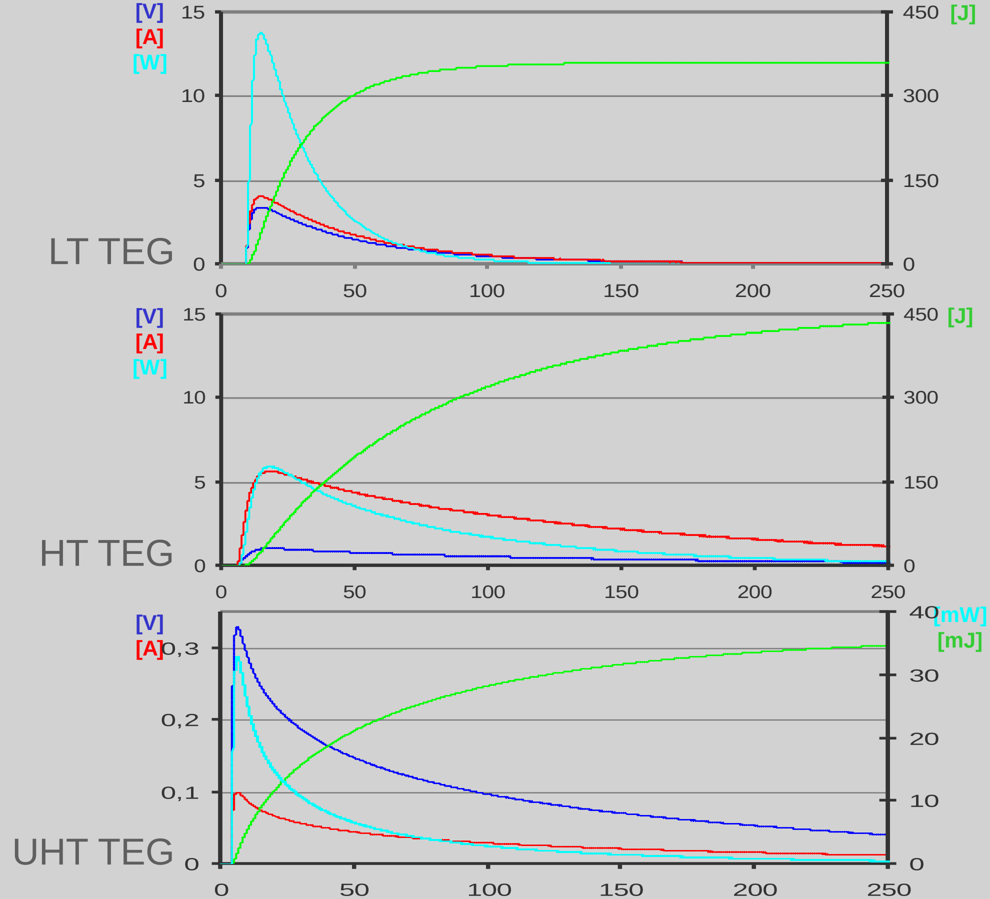
- Evaluation of the principle with internal heat source



Heat
Hot Buffer
TEG
Cold Buffer



TEG with internal Heat source looks feasible

TEG with internal Heat

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- How to provide the internal heat energy
  - as an example $Fe/KClO_4$

to generate	100 mJ	1,000 mJ	*electrical output*
requires	2.5 mm^3	25 mm^3	η_{tot} = 1%
	25 mm^3	250 mm^3	η_{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 µJ/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 ÷ 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 ≥ 500 µJ/mm^3 (100 x setback generators density)

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

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Thank you for your Attention!

Any Questions, Comments, Objections, …

Diehl & Eagle Picher Contact

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Diehl & Eagle Picher in a Nutshell

DIEHL & EAGLE PICHER
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- 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

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- 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