NATIONAL ACADEMY OF SCIENCES OF UKRAINE

ACTIVITIES OF INSTITUTE OF THERMOELECTRICITY OF THE NATIONAL ACADEMY OF SCIENCE, UKRAINE

Doctor
Lukyan I. Anatychuk

E-mail: ite@inst.cv.ua
Web: http://ite.cv.ukrtel.net

Fax: (380-3722)-41917,
Tel.: (380-3722)-44422

Box 86, General Post Office,
Chernivtsi, 58002, Ukraine

UKRAINE

Poland
Chernivtsi
Romania
Black Sea
Institute of Thermoelectricity

Physics and Technical Institute, Saint-Petersburg

Chernivtsi National University

1991

INSTITUTE
of Thermoelectricity

1991

ALTEC - LTD Company

RAPID

Design office
“Phonon”

1980

Journal
of Thermoelectricity

1993

Thermoelectric Department,
Chernivtsi National University

1973

Council for Scientific
Degrees Conferment

1995

Activities of Institute of Thermoelectricity of the National Academy of Sciences, Ukraine

R & D lines

- Microscopic theory
- Phenomenological theory
- Thermoelectric material science
- Materials technology
- Modules technology
- Measuring instruments
- Thermoelectric generators
- Thermoelectric cooling devices

Phenomenological theory of thermoelectricity development

Maxwell's equations
for nonisotermal medium

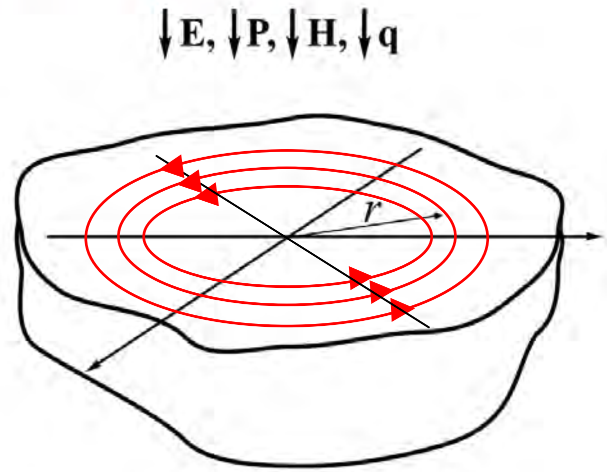
$$\operatorname{div} \vec{D} = 4\pi\delta \qquad (1)$$

$$\operatorname{div} \vec{B} = 0 \qquad (2)$$

$$\operatorname{rot} \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad (3)$$

$$\operatorname{rot} \vec{H} = \vec{j} + \frac{\partial \vec{B}}{\partial t} \qquad (4)$$

$$\boxed{\vec{j}\left(\vec{r},t\right) = \hat{\sigma}\vec{E} - \hat{\alpha}\hat{\sigma}\nabla T\left(\vec{r},t\right)} \qquad (5)$$



$$\hat{\rho}\left(\operatorname{rot} \vec{H} - \frac{\partial \vec{D}}{\partial t}\right) = \vec{E} - \alpha\nabla T \qquad (6)$$

$$\operatorname{rot} \hat{\rho}\left(\operatorname{rot} \vec{H} - \frac{\partial \vec{D}}{\partial t}\right) = \frac{\partial \vec{B}}{\partial t} - \operatorname{rot} \alpha\nabla T \qquad (7)$$

Generalized Faraday's Law

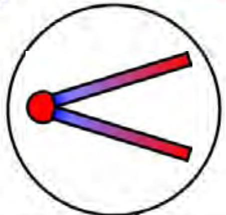
$$\boxed{\operatorname{rot}\hat{\rho}\,\vec{j}_{total} = -\frac{\partial\vec{B}}{\partial t} - \operatorname{rot}\hat{\alpha}\nabla T} \qquad (8)$$

$$\frac{\partial\vec{B}}{\partial t} = 0$$

The Law of Thermoelectric Current Induction

$$\boxed{\operatorname{rot}\hat{\rho}\,\vec{j}_{total} = -\operatorname{rot}\alpha\nabla T} \qquad (9)$$

Media and actions that can result in thermoelectric power conversion



$$\mathrm{rot}\,\vec{j} \neq 0 \qquad \mathrm{rot}\,\hat{\alpha}\nabla T \neq 0 \qquad (11)$$

Media / Fields	σ	$\sigma(x_i)$	σ	$\sigma(x_i)$	σ_{ik}	σ	σ_{ik}	$\sigma(x_i)$	$\sigma(x_i)$	$\sigma(x_i)$	σ_{ik}	σ	$\sigma(x_i)$	$\sigma_{ik}(x_i)$	$\sigma(x_i)$	$\sigma_{ik}(x_i)$
	α	α	$\alpha(x_i)$	$\alpha(x_i)$	α	α_{ik}	α_{ik}	α	α_{ik}	α_{ik}	$\alpha(x_i)$	$\alpha_{ik}(x_i)$	$\alpha_{ik}(x_i)$	$\alpha(x_i)$	$\alpha_{ik}(x_i)$	$\alpha_{ik}(x_i)$
ΔT	0	0			0			0								
$\Delta T, H$																
$\Delta T, P$																
$\Delta T, E$																
$\Delta T, H, P$																
$\Delta T, H, E$																
$\Delta T, H, P, E$																
$\nabla' T$																

0 - conversion is impossible

- in use

- under study

- not studied yet

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Medium / Field	σ / α	$\sigma(x_i)$ / α	σ / $\alpha(x_i)$	$\sigma(x_i)$ / $\alpha(x_i)$	σ_{ik} / α	σ / α_{ik}	σ_{ik} / α_{ik}	$\sigma(x_i)$ / α	$\sigma(x_i)$ / α_{ik}	$\sigma(x_i)$ / α_{ik}	σ_{ik} / $\alpha(x_i)$	σ / $\alpha_{ik}(x_i)$	$\sigma(x_i)$ / $\alpha_{ik}(x_i)$	$\sigma_{ik}(x_i)$ / $\alpha(x_i)$	$\sigma(x_i)$ / $\alpha_{ik}(x_i)$	$\sigma_{ik}(x_i)$ / $\alpha_{ik}(x_i)$
ΔT	0	0			0			0								
$\Delta T, H$																
$\Delta T, P$																
$\Delta T, E$																
$\Delta T, H, P$																
$\Delta T, H, E$																
$\Delta T, H, P, E$																
∇T																

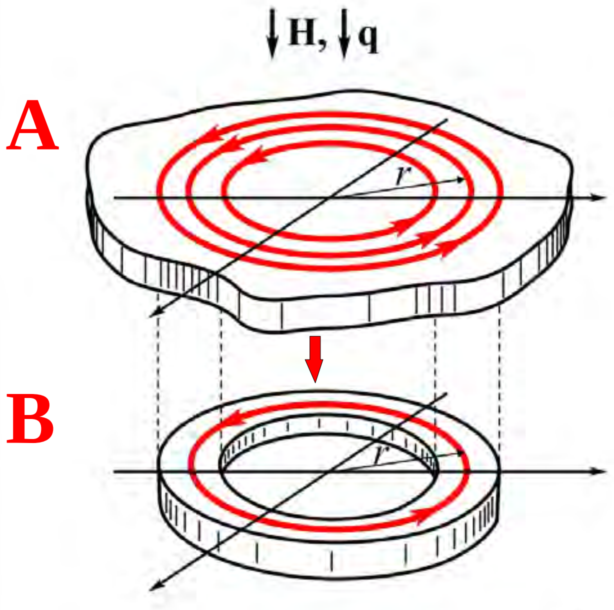
Conclusions

1. Thermoelectricity is still on the initial stage of its development. The majority of possibilities are still unresearched.

2. Thermocouple (on which modern thermoelectricity is based) is just a particular case of a thermoelectric power converter.

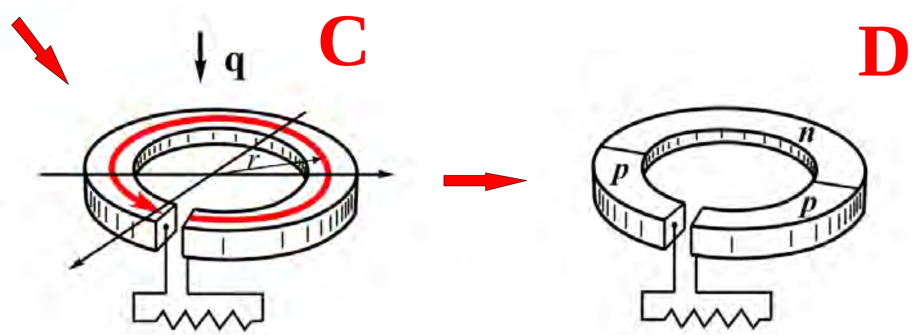
3. The Table allows to realize a systematic approach to planning thermoelectricity research. As for its significance, it reminds Mendeleyev's Table in chemistry.

Method for devising new thermoelement types



Medium / Field	σ	$\sigma(x_i)$	σ	$\sigma(x_i)$	σ_{ik}	σ	σ_{ik}	$\sigma(x_i)$	$\sigma(x_i)$	$\sigma(x_i)$	σ_{ik}	σ	$\sigma(x_i)$	$\sigma_{ik}(x_i)$	$\sigma(x_i)$	$\sigma_{ik}(x_i)$
	α	α	$\alpha(x_i)$	$\alpha(x_i)$	α	α_{ik}	α_{ik}	α	α_{ik}	α_{ik}	$\alpha(x_i)$	$\alpha_{ik}(x_i)$	$\alpha_{ik}(x_i)$	$\alpha(x_i)$	$\alpha_{ik}(x_i)$	$\alpha_{ik}(x_i)$
ΔT	0	0			0			0								
$\Delta T, H$																
$\Delta T, P$																
$\Delta T, E$																
$\Delta T, H, P$																
$\Delta T, H, E$																
$\Delta T, H, P, E$																
$\nabla' T$																

thermoelectric power converter



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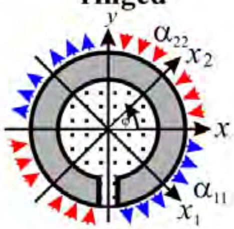
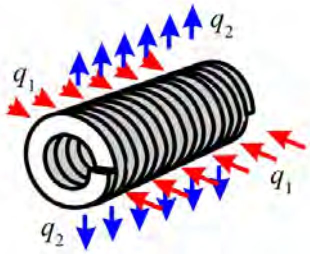
Models of eddy thermoelements

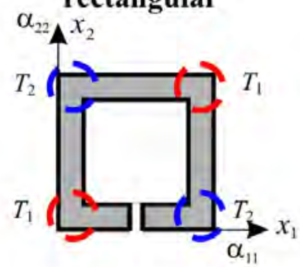
Anisotropic ringed



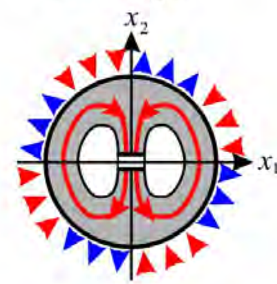
Anisotropic ringed spiral



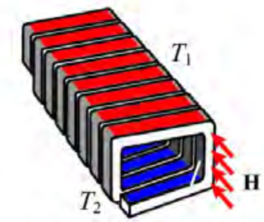
Longitudinal-type anisotropic rectangular



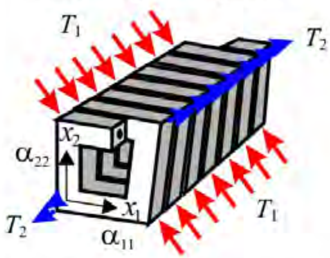
Double circular anisotropic



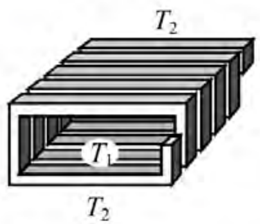
Magnetothermoelectric spiral



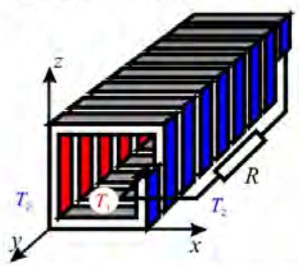
Longitudinal-type anisotropic rectangular spiral



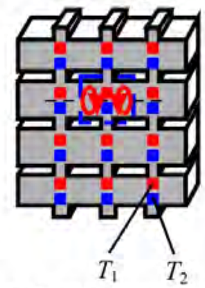
Transverse-type anisotropic spiral rectangular



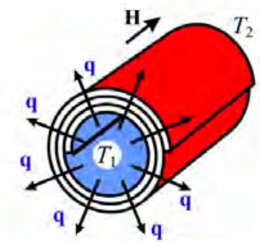
Spiral anisotropic piezothermoelement



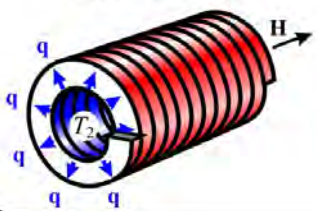
Multi-cell anisotropic



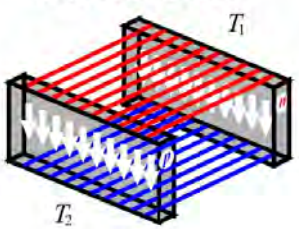
Rolled galvanomagnetic thermoelement with a radial thermal flow



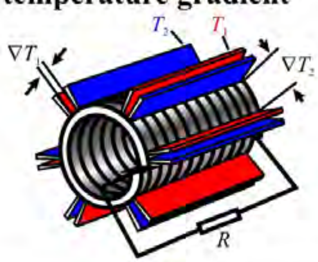
Spiral galvanomagnetic thermoelement with a radial thermal flow



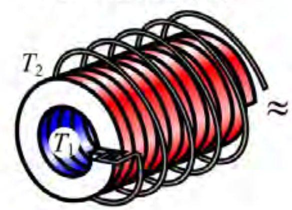
Double anisotropic short-circuited



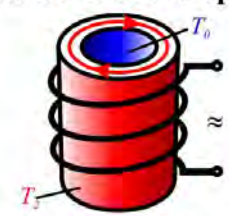
Spiral thermoelement with a large temperature gradient



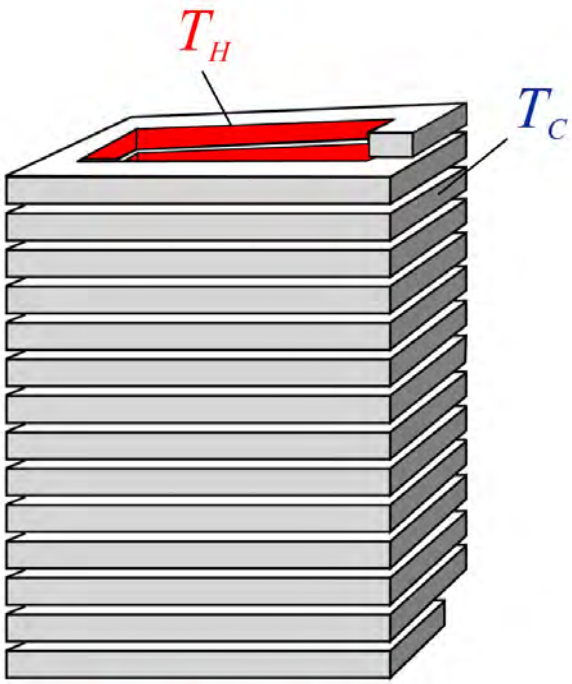
Spiral galvanomagnetic thermoelement with alternating current supply



Cylindrical galvanomagnetic thermoelement with inductive coupling



Spiral converter of anisotropic material



$T_H - T_C = 50$ K

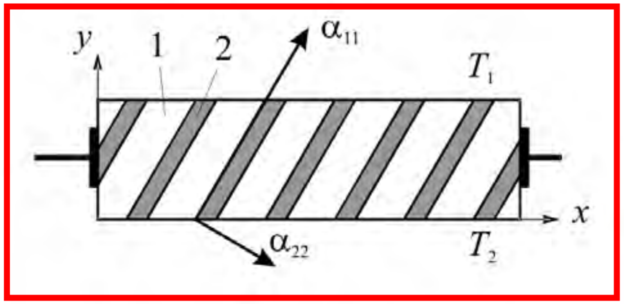
$V = 0.5$ cm^3

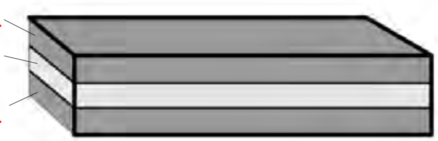
$U = 10\ 000$ V

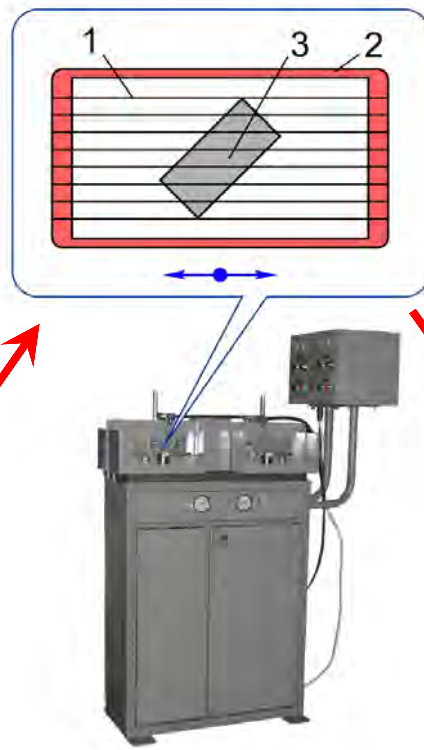
Resolution 10^{-8} W

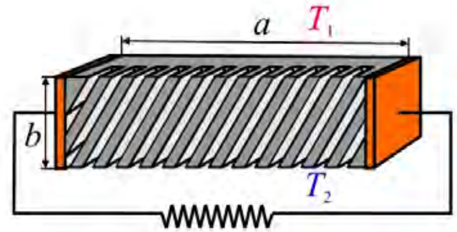
Microcalorimeter appearance

Artificially anisotropic power convertes

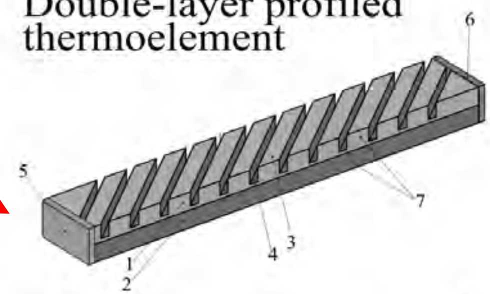




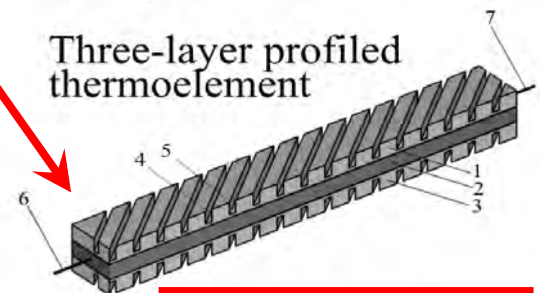




Double-layer profiled thermoelement



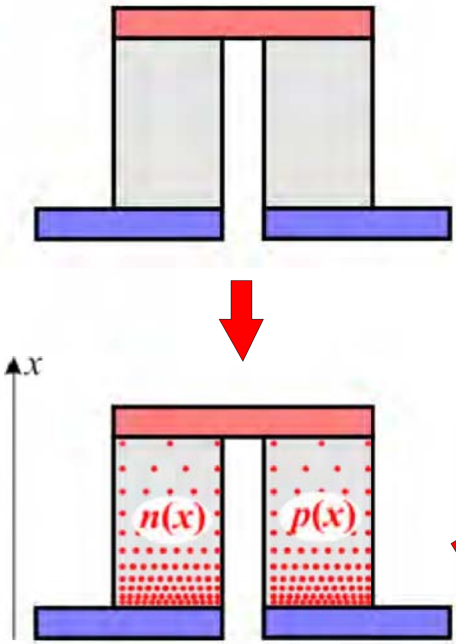
Three-layer profiled thermoelement



$$\eta_3 \approx 10\eta_A$$

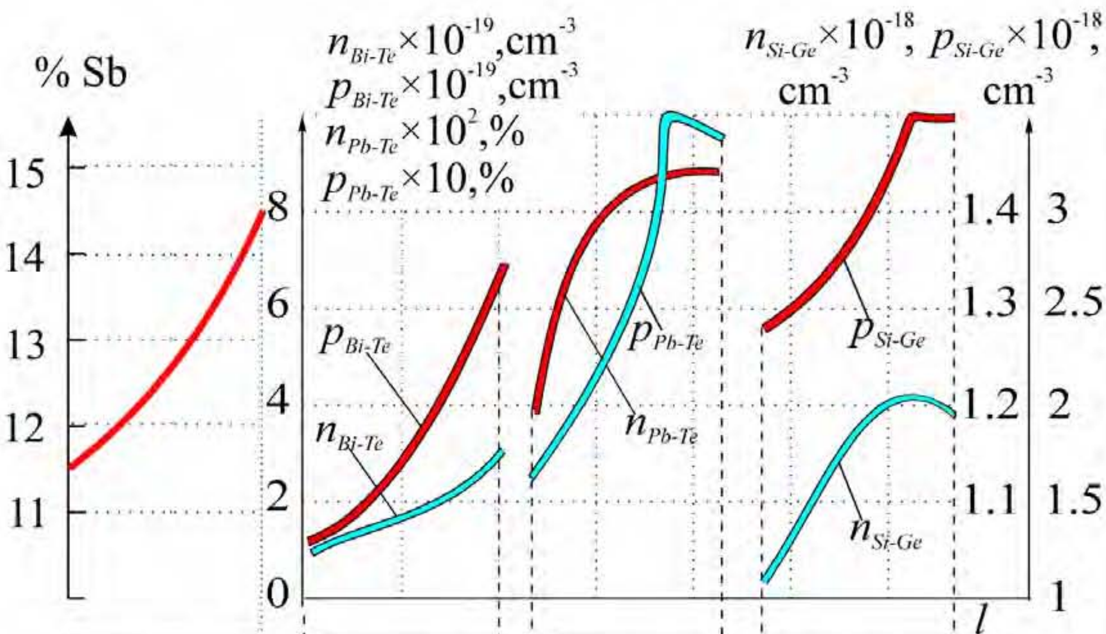
Bi-Te Bi-Sn

Programmable inhomogeneous media - FGM



Efficiency increase

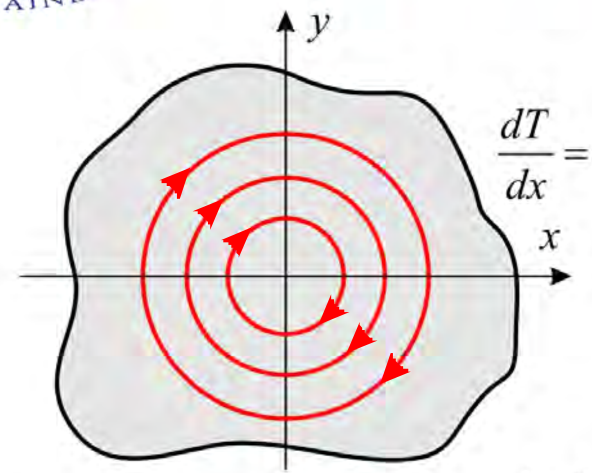
Optimal inhomogeneities



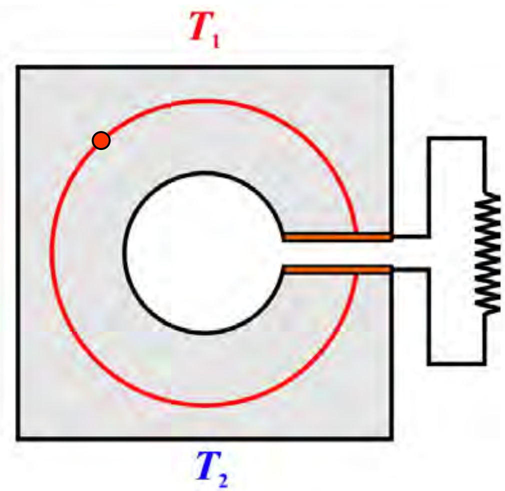
Bi-Sb	Bi-Te	Pb-Te	Si-Ge
120-160 K	300 K	600 K	900 K
1.6	**1.2**	**1.16**	**1.1**

1300 K

Spiral inhomogeneous converter



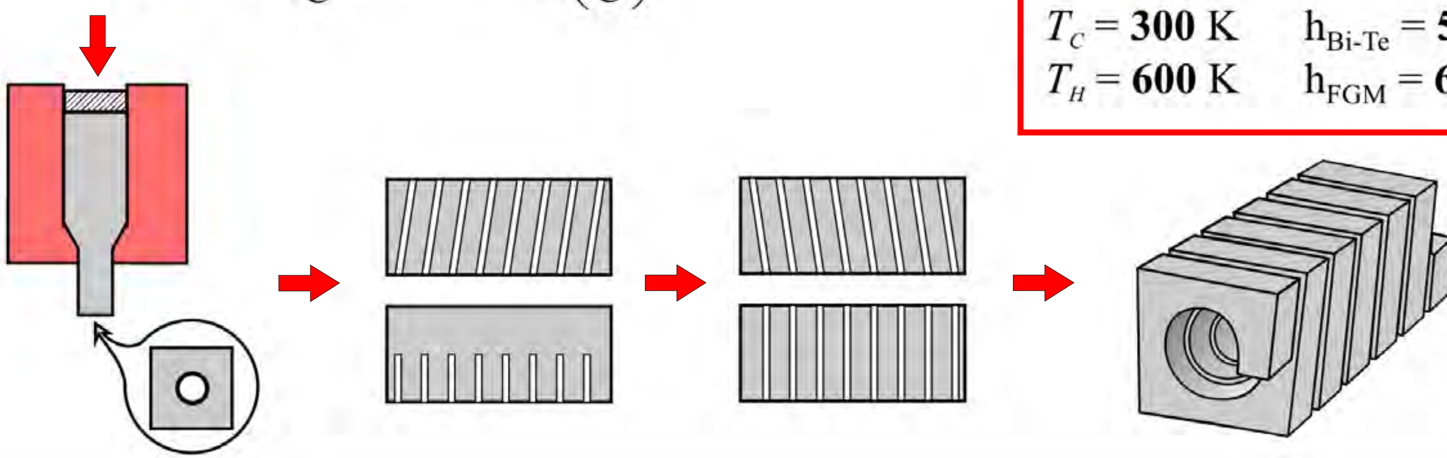
$$\frac{dT}{dx} = \text{const};$$



$$\alpha(x) = B + D\frac{x}{C}; \quad \sigma = A\exp\left(\frac{x}{C}\right).$$

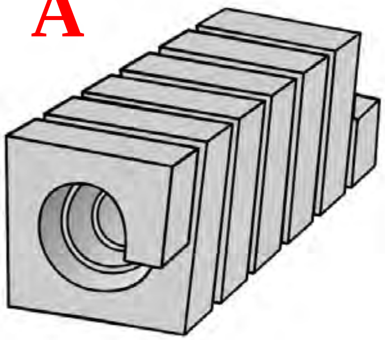
T_C = **300** K $\quad$ $h_{Bi\text{-}Te}$ = **5%**

T_H = **600** K $\quad$ h_{FGM} = **6.5%**

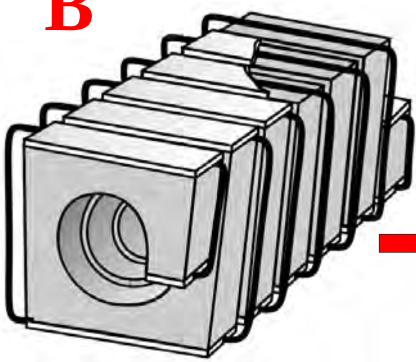


Spiral thermoelectric generator

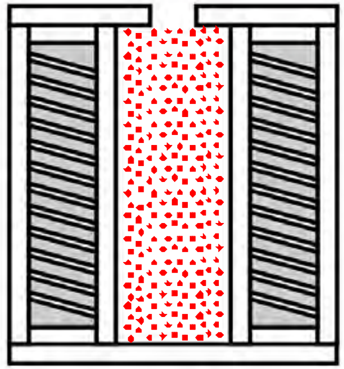
A



B



C



$t_0 = 0.1$ sec

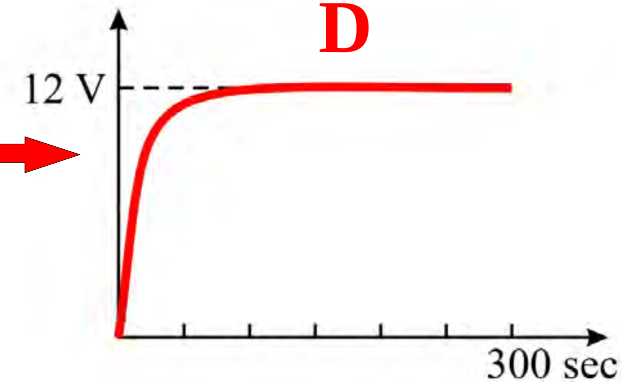
$g = 20 - 80000$

$t = 30$ years

$U = 12$ V

$W = 0.5$ W

D



Number of spiral loops	Fraction of permissible failures	MTBF increase
200	0.01	**205**
200	0.02	**60340**
100	0.02	**412**
100	0.04	**71000**

Low-power modules and generators

$S_0 = 0.1\text{x}0.1 - 0.5\text{x}0.5$ mm

$l = 1.0 - 20$ mm

$N = 94 - 7560$

A	30 – 150 °C	$\eta = 2.8 - 3.3\%$
B	30 – 250 °C	$\eta = 5.5 - 6.0\%$
C	30 – 250 °C with redundancy	$\eta = 4.5 - 5.5\%$

Portable

$U = 3.5 - 6$ V
$W = 1$ W
$t = 10$ h

$U = 3$ V
$W = 10$ mW
$t = 125$ h

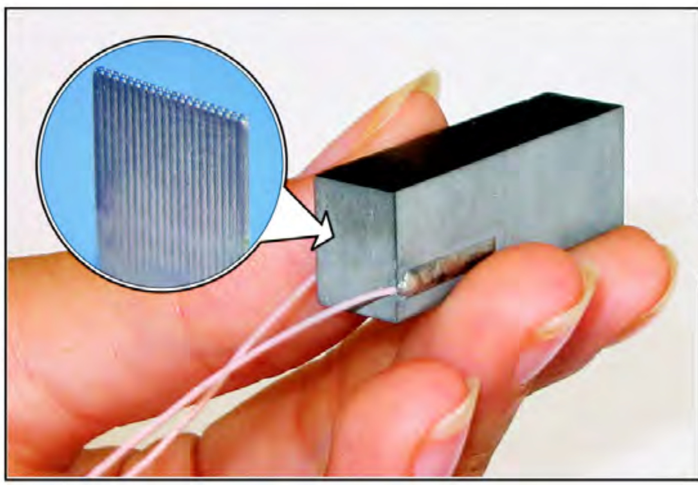
Soil

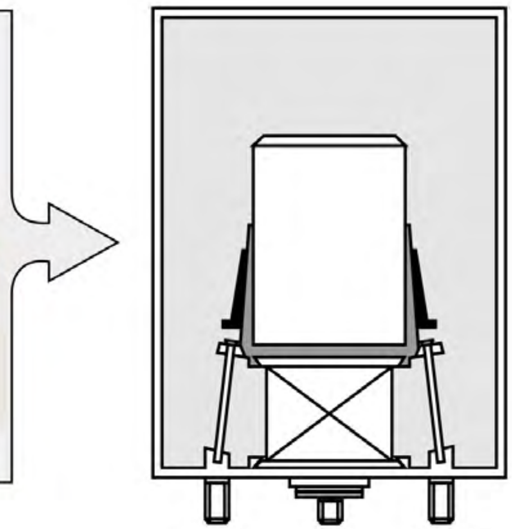
$U = 1.5$ V

$W = 1.2$ mW

$t = 30$ years

Space-purpose generator



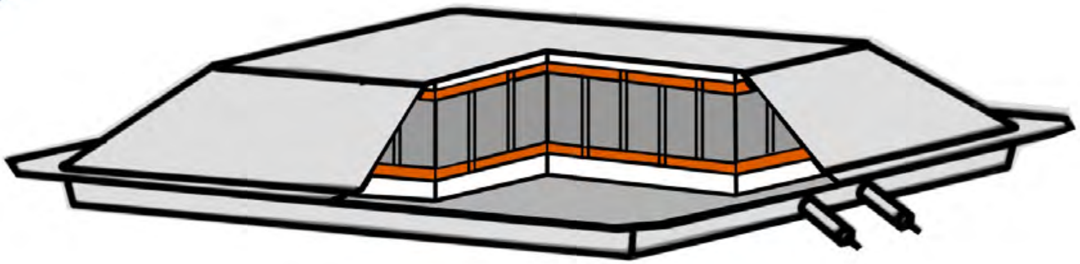


6 V, 0.5 W

Modules for heat recovery

$$\boxed{M_0 = \frac{\$}{W}}$$

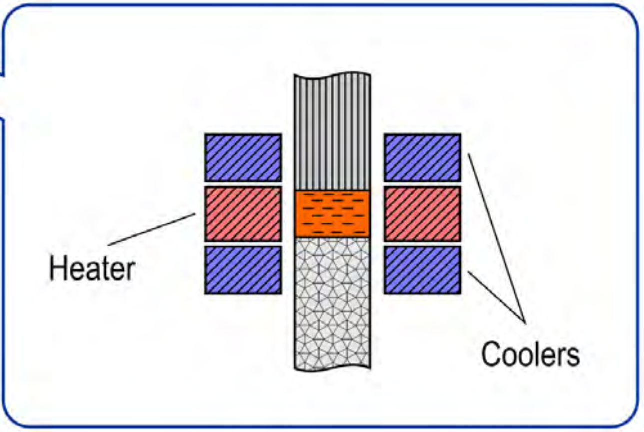
Specific cost	M_0	→	**< 1.5 - 0.5** $/W
Operating temperature range	ΔT	→	**50 - 350** °C
Lifetime	t	→	**100 000** hours
Cyclic stability		→	**100 000**
Efficiency		→	**> 5 - 6** %




Altec 1061
№ 617
UA

Module type	Size, mm	U_{max}, V	I_{max}, A	W_{max}, W	Q_{max}, W	η_{max}, %	M
Altec 1060	40x40x4.0	4.8±0.2	2.1±0.07	10.0±0.3	143±5	7.0±0.3	1
Altec 1061	40x40x4.0	2.4±0.1	4.2±0.15	10.0±0.3	143±5	7.0±0.3	1
Altec 1062	40x40x4.0	1.2±0.05	8.3±0.3	10.0±0.3	143±5	7.0±0.3	80
Altec 1063	40x40x4.0	0.6±0.03	16.7±0.5	10.0±0.3	143±5	7.0±0.3	350
Altec 1064	40x40x4.0	0.28±0.02	35.7±1	10.0±0.3	143±5	7.0±0.3	600
Altec 1065	30x30x4.0	1.04±0.05	5.9±0.2	6.1±0.2	87±5	7.0±0.3	1
Altec 1066	30x30x4.0	0.51±0.02	12.0±0.4	6.1±0.2	87±5	7.0±0.3	50
Altec 1067	30x30x4.0	0.34±0.02	17.9±0.6	6.1±0.2	87±5	7.0±0.3	190
Altec 1068	30x30x4.0	0.17±0.01	35.9±1.5	6.1±0.2	87±5	7.0±0.3	400
Altec 1069	30x60x4.0	2.2±0.1	4.5±0.1	10.0±0.3	143±5	7.0±0.3	1
Altec 1070	30x60x4.0	1.0±0.05	10.0±0.4	10.0±0.3	143±5	7.0±0.3	90
Altec 1071	30x60x4.0	0.65±0.03	15.4±0.6	10.0±0.3	143±5	7.0±0.3	270
Altec 1072	30x60x4.0	0.32±0.02	31.2±2	10.0±0.3	143±5	7.0±0.3	520
Altec 1073	30x60x4.0	0.16±0.01	56.2±3	9.0±0.3	152±5	5.9±0.3	840
Altec 1074	60x60x4.0	3.8±0.2	5.4±0.2	20.6±0.6	294±10	7.0±0.3	1
Altec 1075	60x60x4.0	1.9±0.1	10.8±0.4	20.6±0.6	294±10	7.0±0.3	150
Altec 1076	60x60x4.0	1.3±0.05	15.5±0.6	20.1±0.6	287±10	7.0±0.3	450
Altec 1077	60x60x4.0	1.0±0.05	20.1±0.7	20.1±0.6	287±10	7.0±0.3	580
Altec 1078	60x60x4.0	0.6±0.03	33.5±1.5	20.1±1.5	287±10	7.0±0.3	940
Altec 1079	60x60x4.0	0.31±0.02	56.5±3	17.5±0.6	297±10	5.9±0.3	1500
Altec 1080	60x60x4.0	0.17±0.01	101.8±5	17.3±0.6	293±10	5.9±0.3	2800
Altec 1081	90x90x4.0	8.6±0.4	5.4±0.2	46.3±2	661±25	7.0±0.3	1
Altec 1082	90x90x4.0	5.3±0.2	8.7±0.4	46.3±2	661±25	7.0±0.3	170
Altec 1083	90x90x4.0	2.8±0.2	14.2±0.5	39.8±0.2	674±25	5.9±0.3	600
Altec 1084	90x90x4.0	1.39±0.07	29.7±1	41.3±2	635±25	6.5±0.3	1140

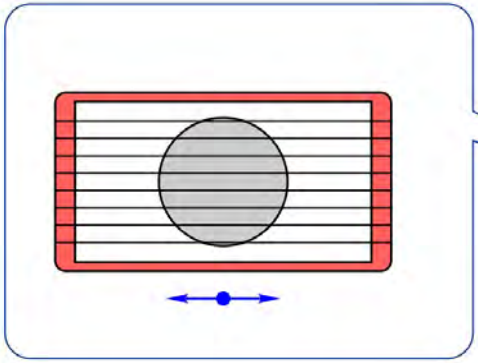
Equipment for the manufacture of Bi-Te thermoelectric material



Productivity

15 kg per day

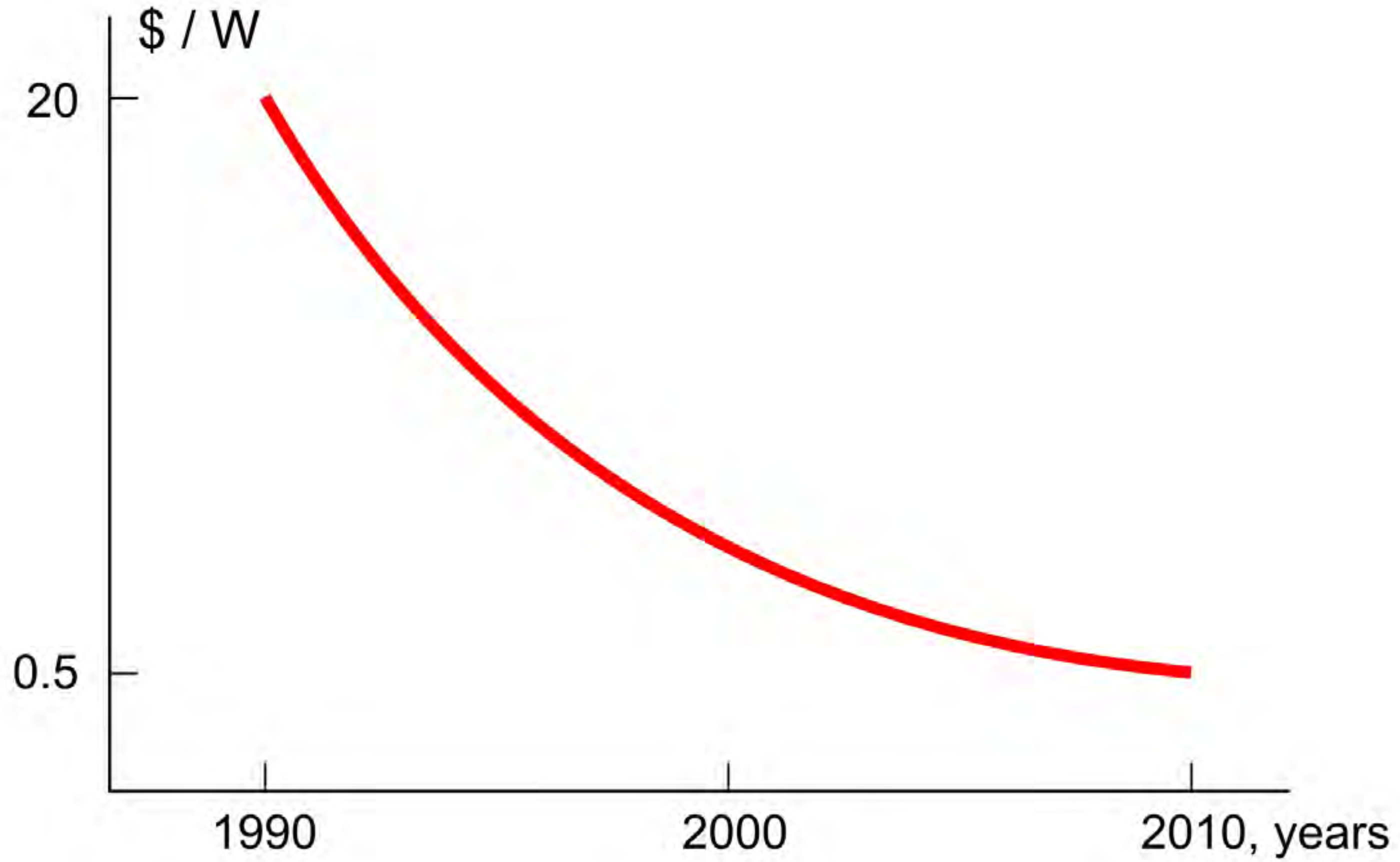
Material cutting equipment



Productivity

40 000 legs per hour

Specific cost reduction of generator modules



Efficiency increase of Bi-Te modules with the use of FGM for module 40x40 mm

	Homogeneous	FGM
COP, %	6.5	7.8
W, W	10	12

2-stage thermoelectric module based on Bi-Te & Ge-Si

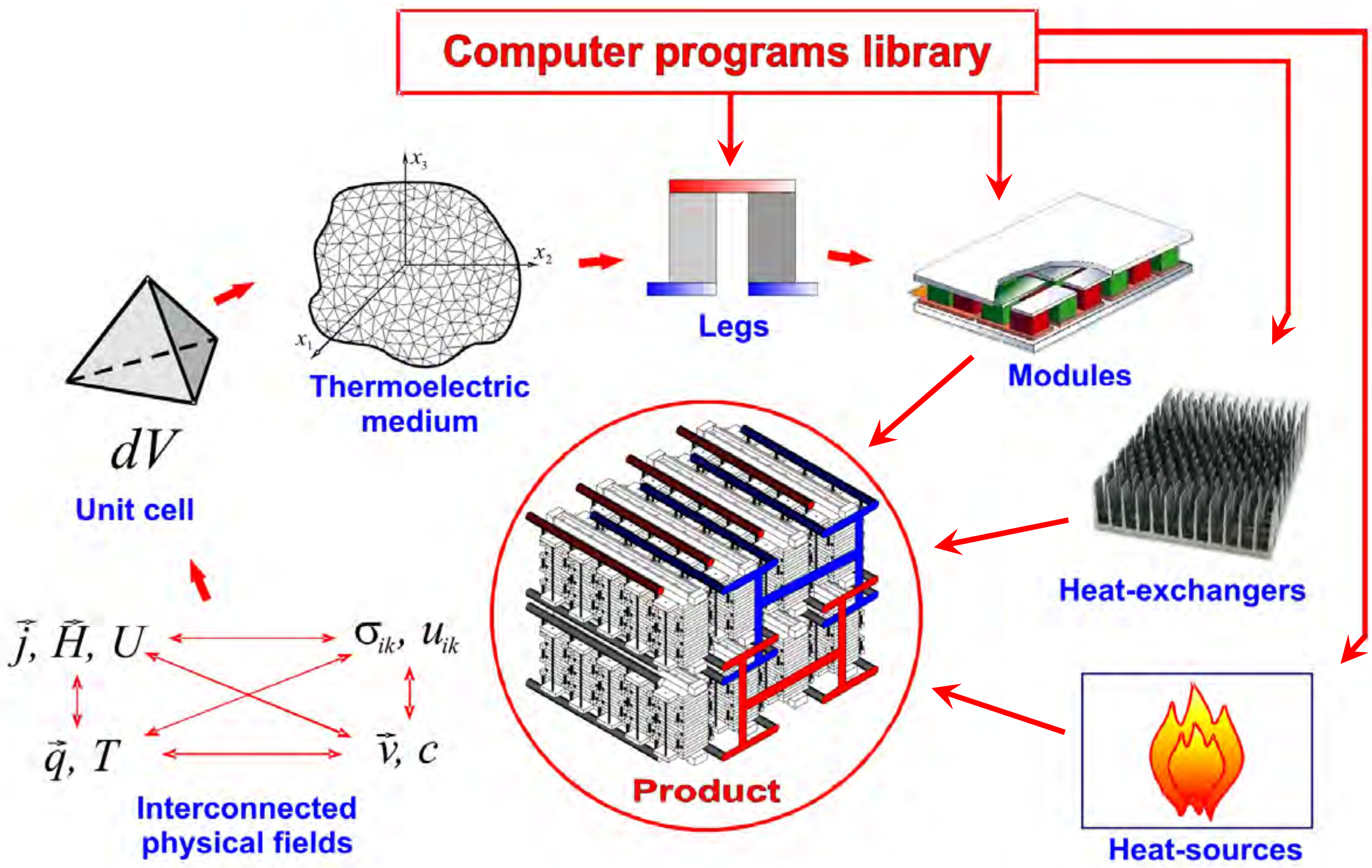
$T_H = 600 - 850^{\circ}C$

$T_C = 50^{\circ}C$

$W = 35\ W$

$\eta\ = 11\text{-}12\%$

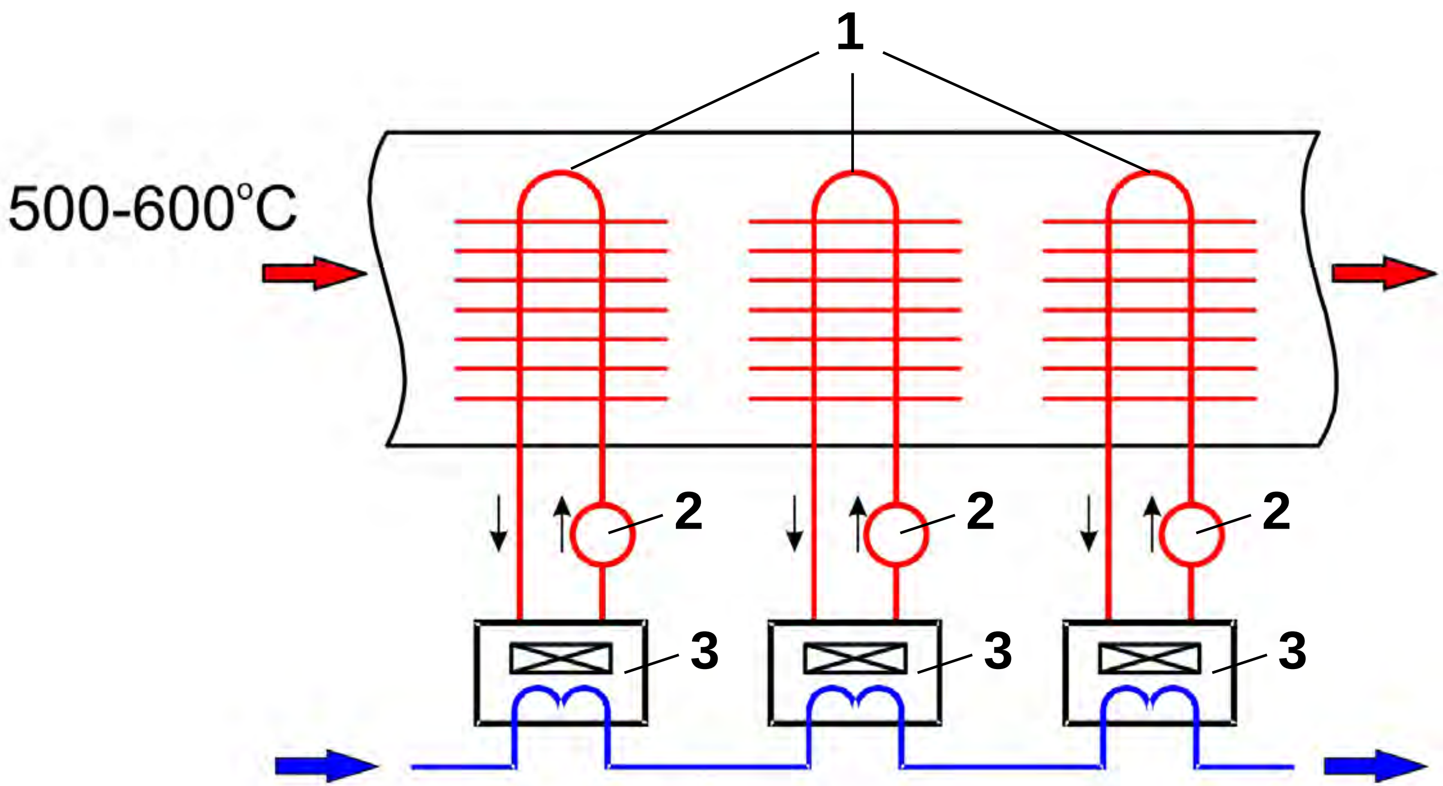
Object-oriented design of thermoelectric products



1 kW thermoelectric generator

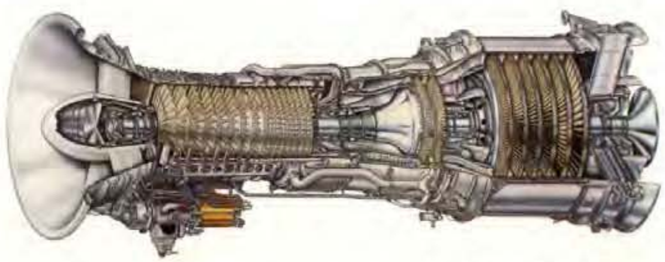
Electric power	**1** kW
Weight	**10** kg
Dimensions	**300x220x150** mm

Generator layout drawing



GENERATOR FOR TURBINE GTG6T

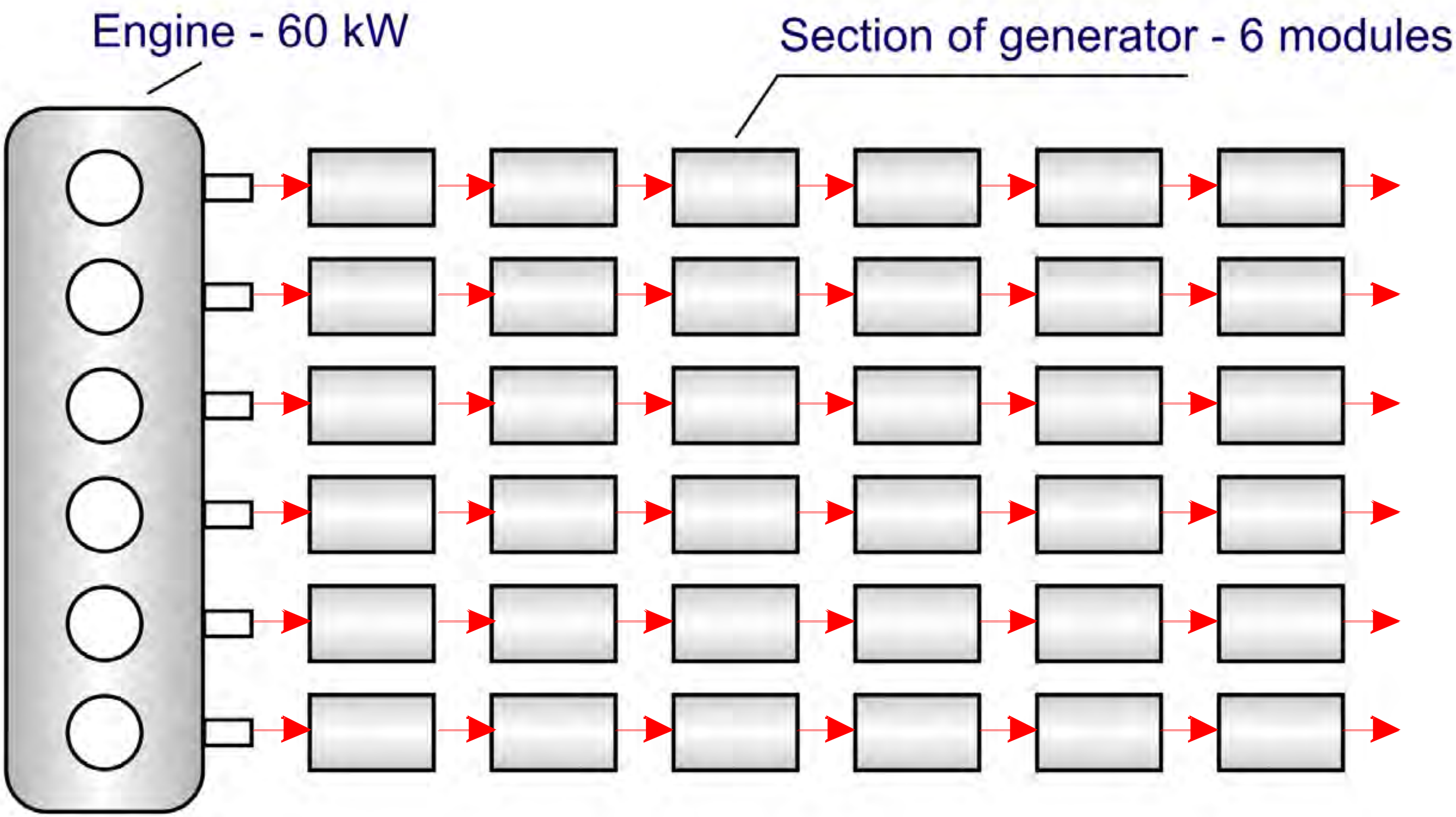
designed by Institute of Thermoelectricity and Paton Electric Welding Institute



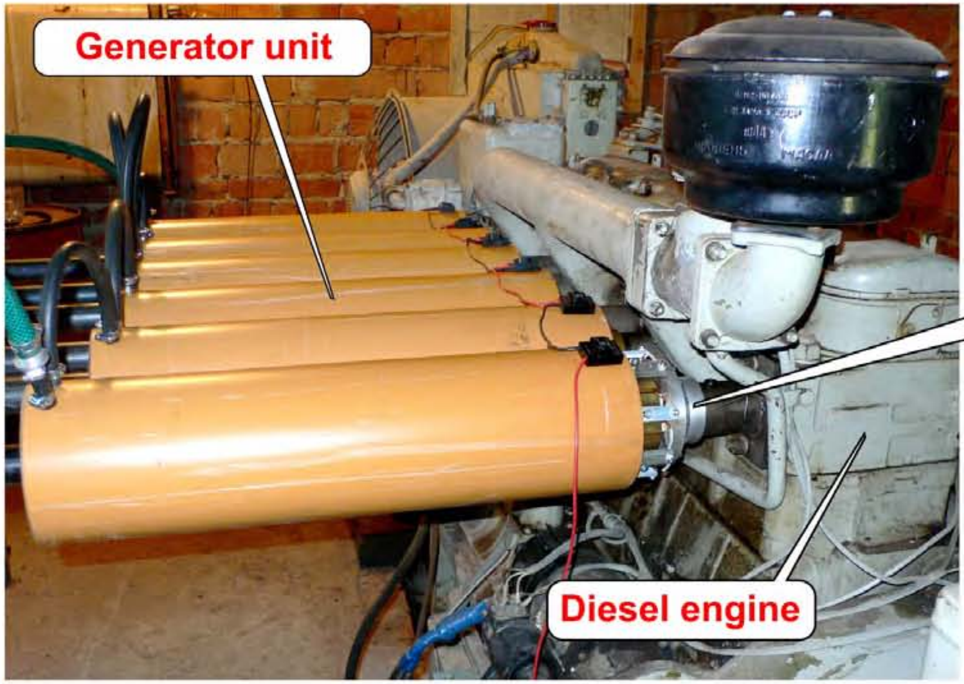
General Electric LM2500 Gas Turbine

Gas flow rate	-	60 kg/s
Inlet gas temperature	-	280°C
Outlet gas temperature	-	150°C
Water flow rate	-	50 kg/s
Inlet water temperature	-	20°C
Outlet water temperature	-	55°C
Electric power	-	0.64 MW
Turbine mechanic power	-	6 MW
Additional electric power due to thermogenerator	-	10.6 %

Thermoelectric generator for stationary diesel



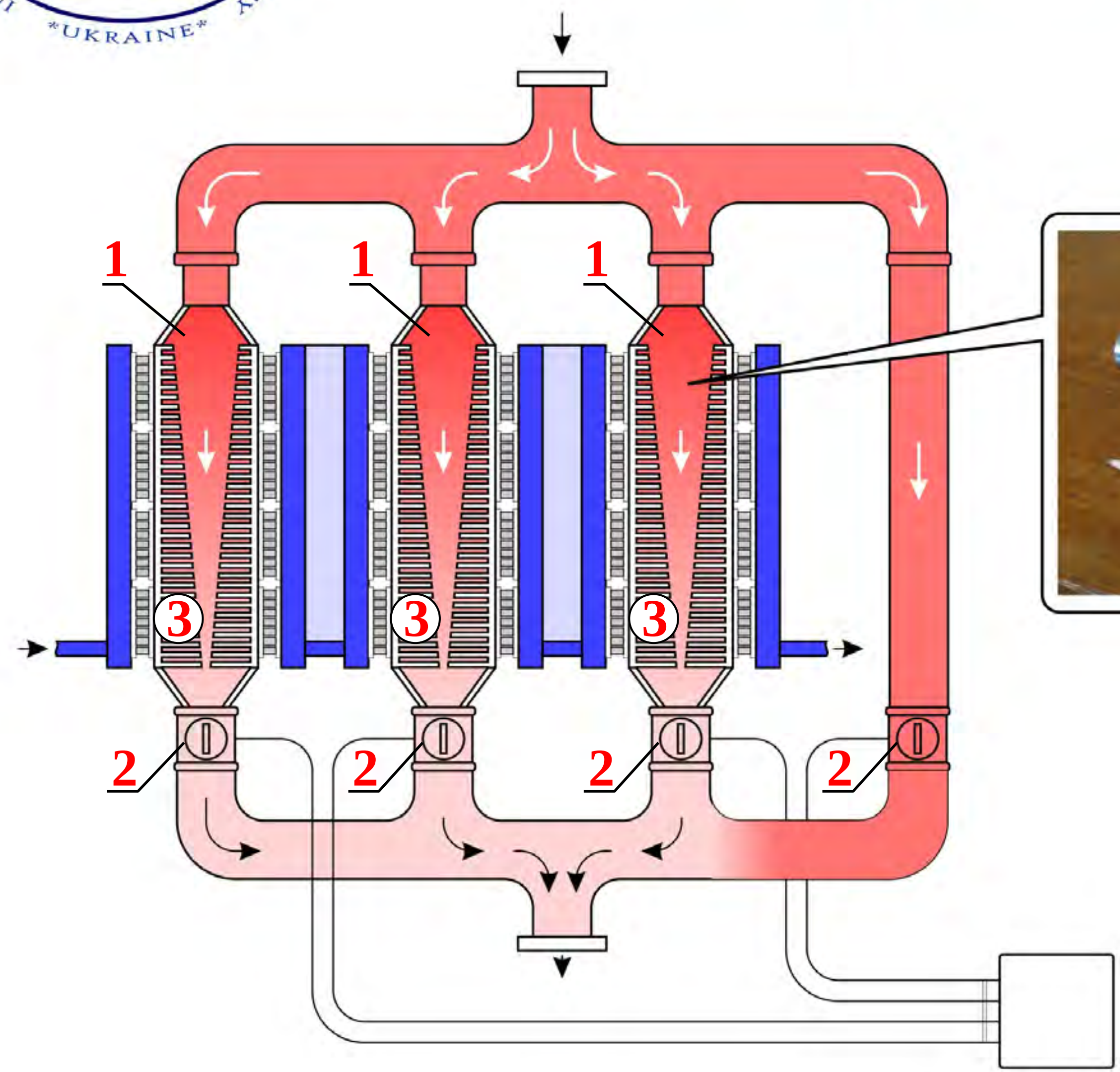
Prototype of diesel generator

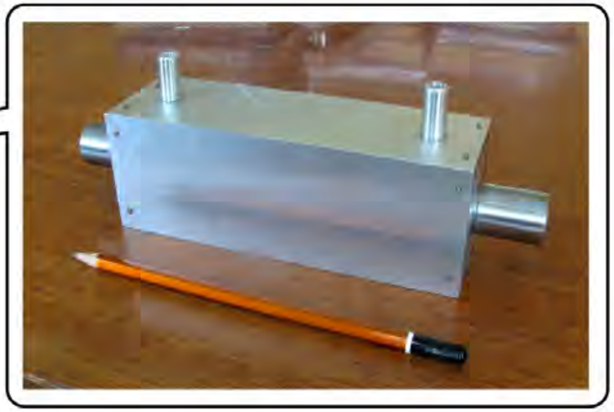


Section fragment

Σ = **2027** W

Vehicular generator



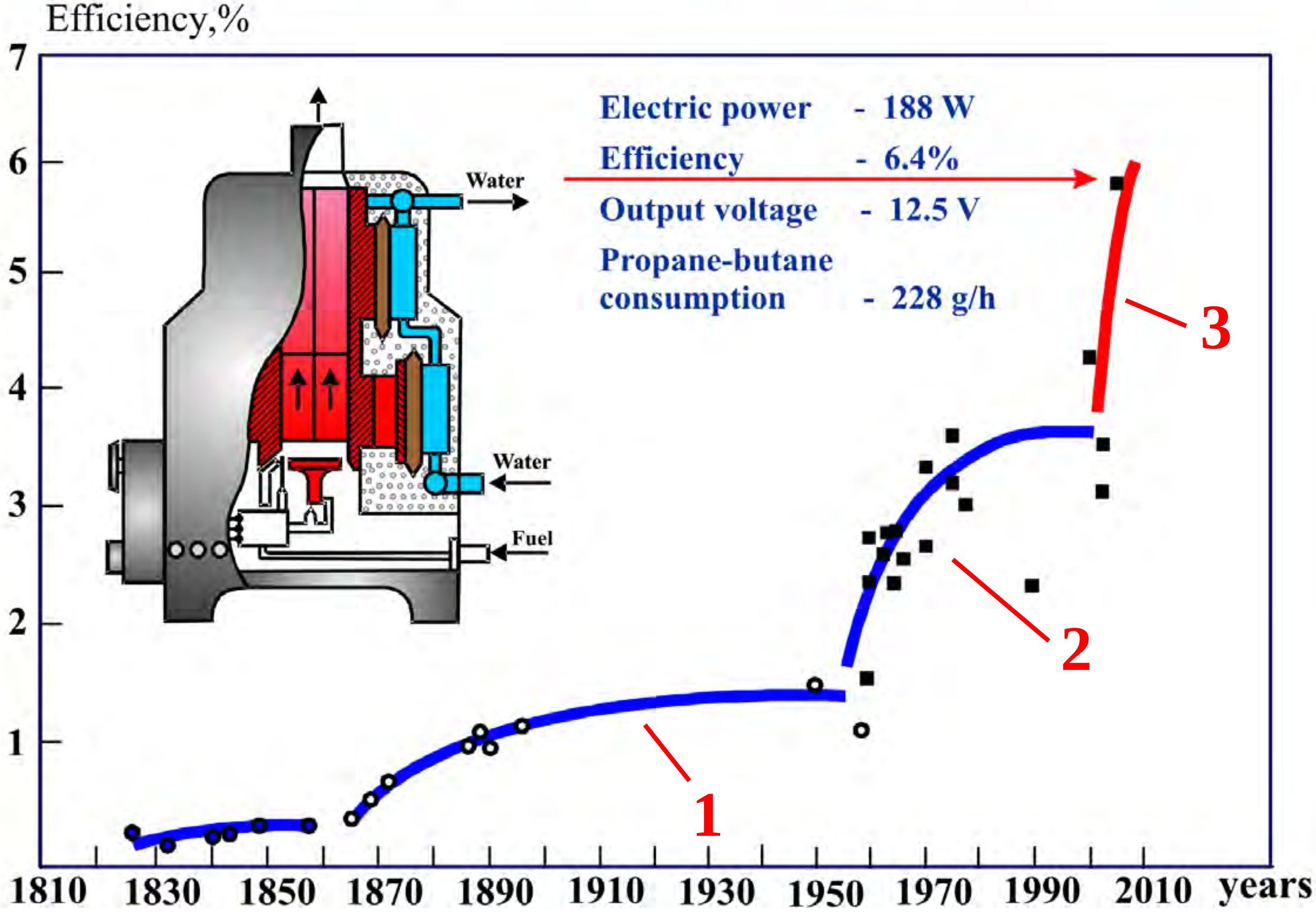


W = 150 W

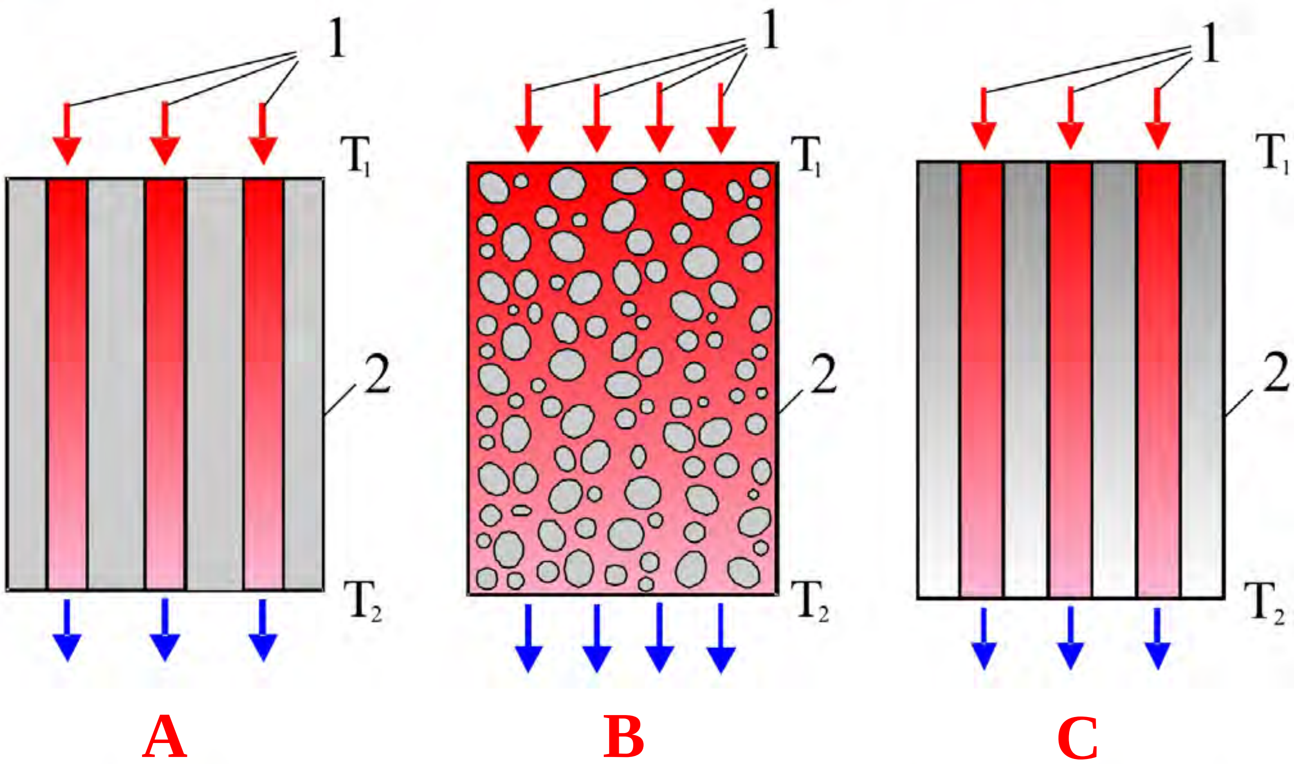
U = 15 V

W x 4 = 600 W

Progress in creating thermoelectric generators with the heat sources utilizing hydrocarbon fuel

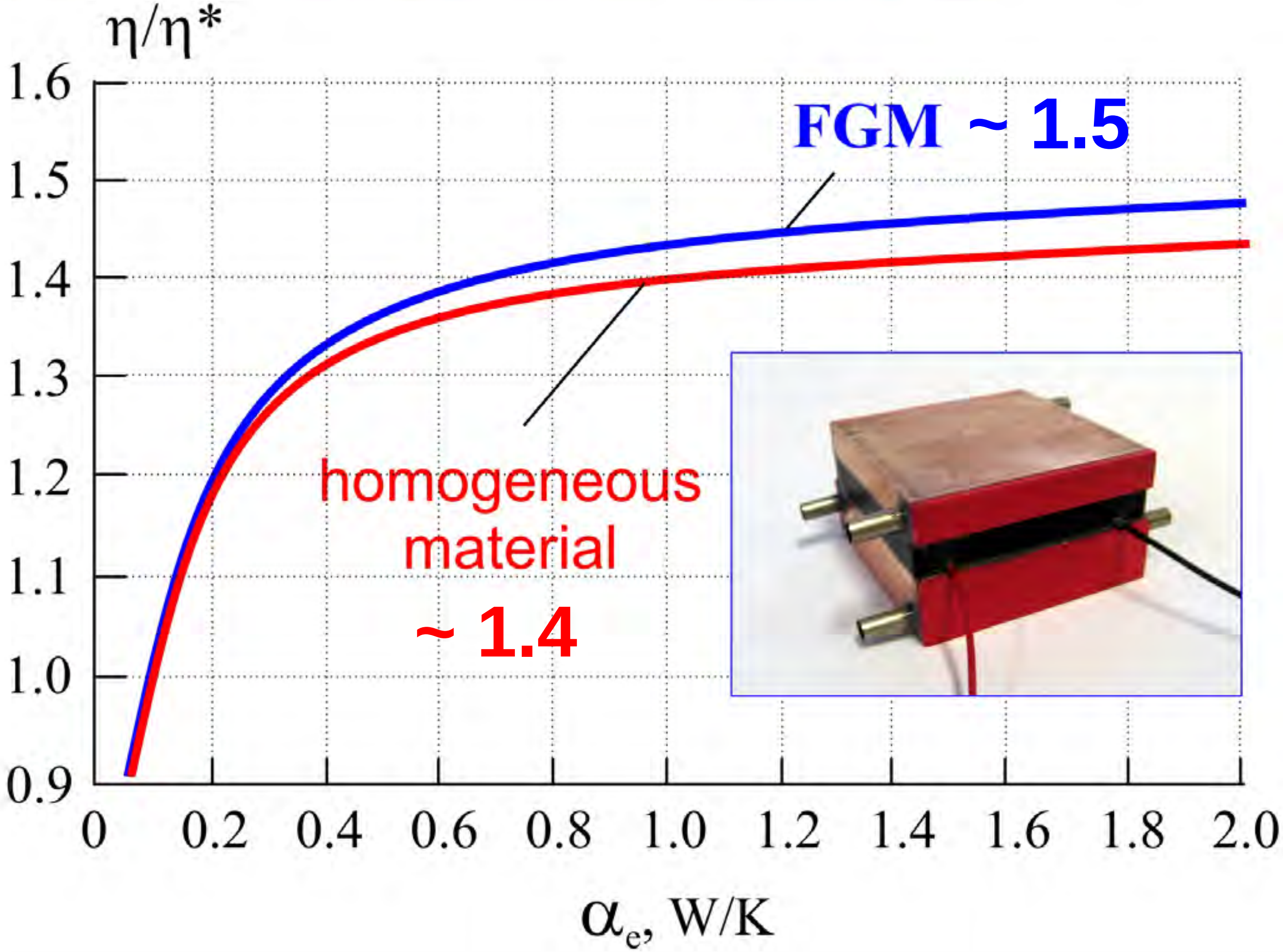


Permeable thermocouple elements

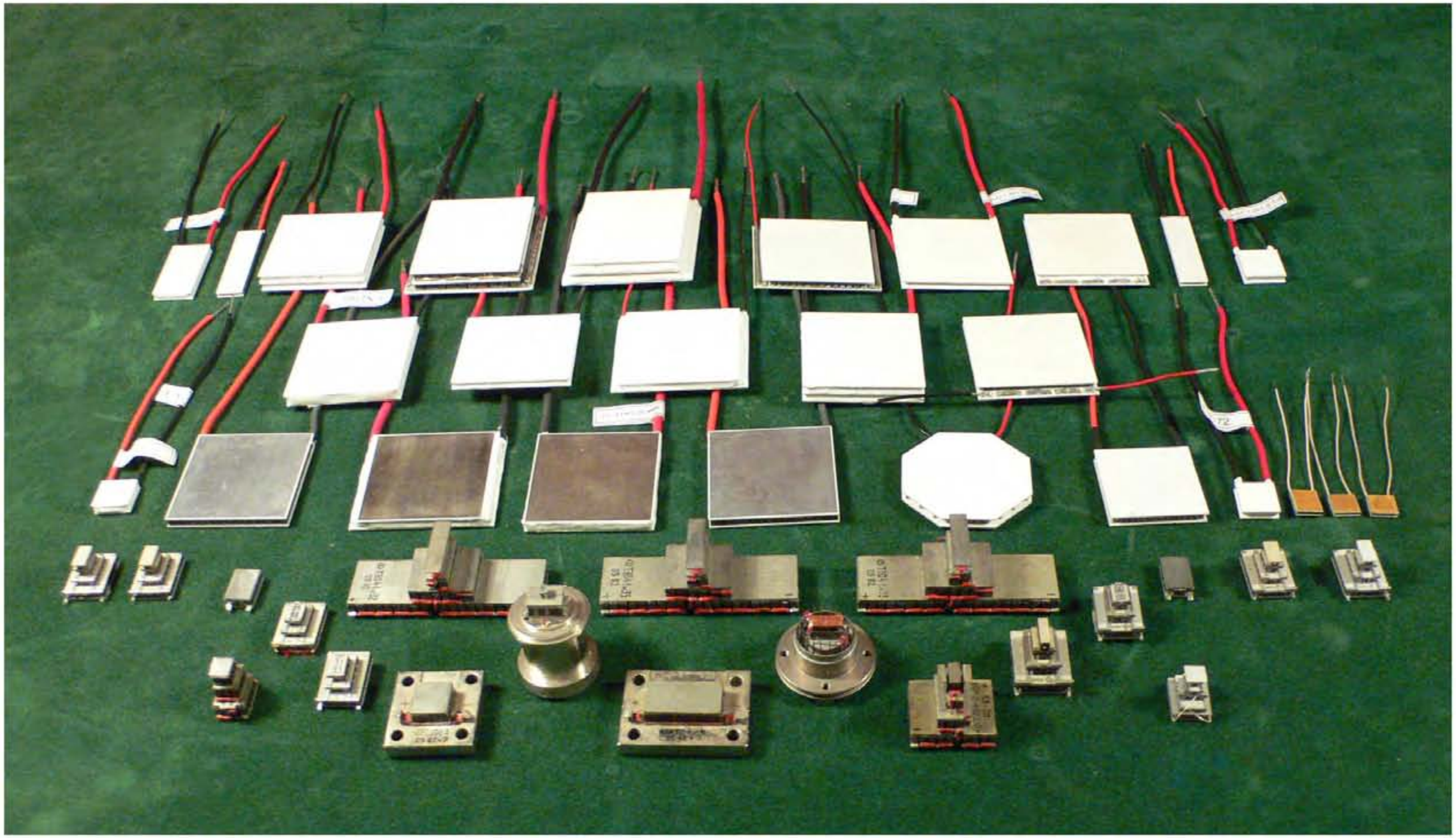


A – material with channels, B – porous material, C – FGM with channels.
1 – combustible gas, 2 –thermocouple element.

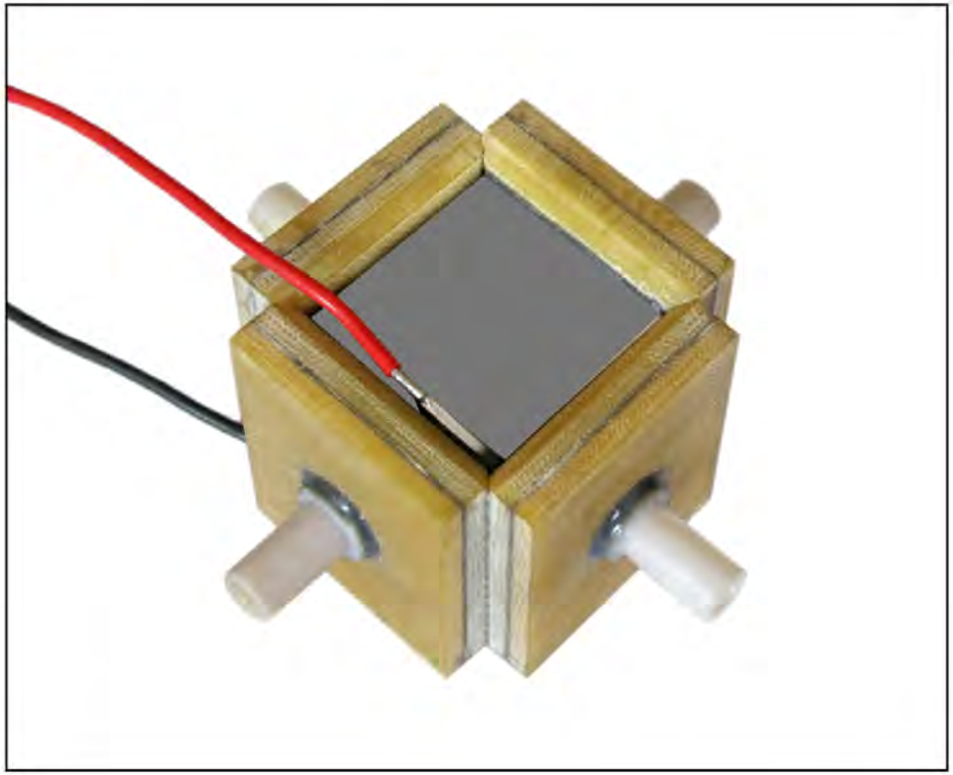
Efficiency of permeable thermoelectric elements



Modules for special applications



Thermoelectric "liquid - liquid" unit



$Q_0 = 200$ W

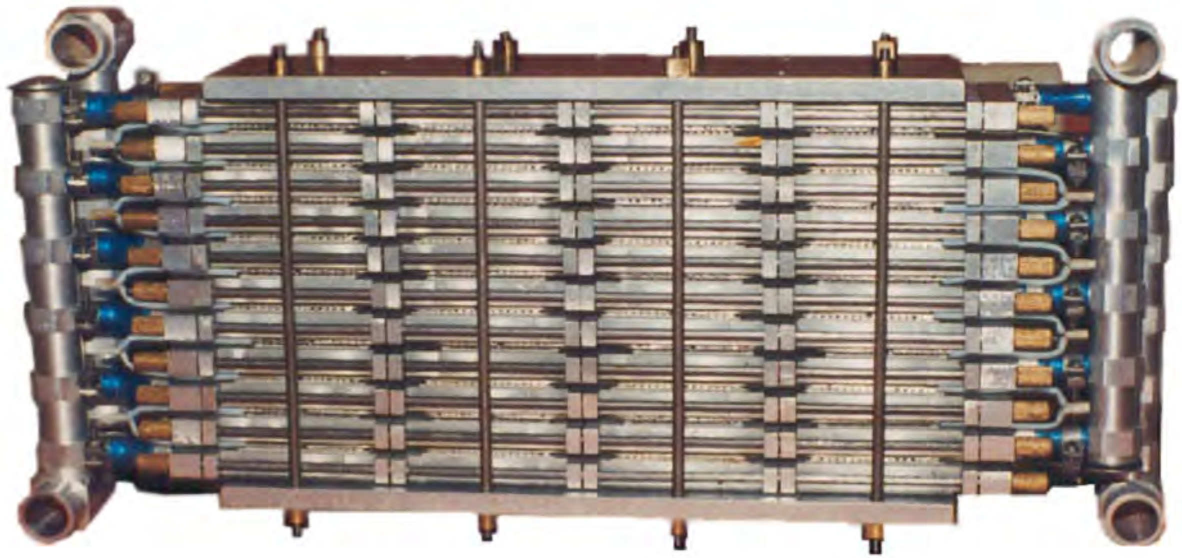
$\varepsilon = 1.8$

$\Delta T = 10^{\circ}$

70x70x60 mm

Thermoelectric air-conditioner Altec-8007

Thermoelectric heat pump for regeneration of water for astronauts

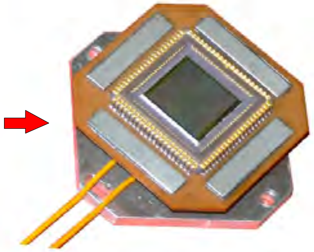


$Q = 800$ W

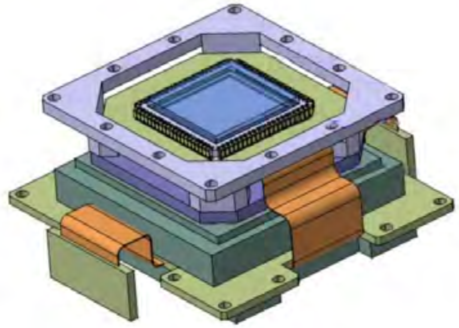
k = 3.2

INSTITUTE OF THERMOELECTRICITY
UKRAINE

Thermoelectric cooling



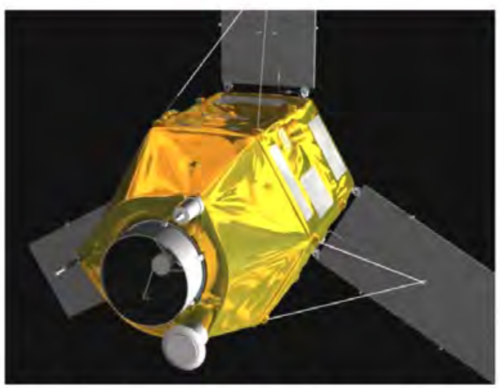
ITE - thermoelectric modules



Star tracker

Telecom - for satellite communications

177 space applications. Among them:



Pleiade - the Earth surface monitoring

Spacebus 4000 - basic platform for integrated research

Dawn - interplanetary space station - Mars, asteroid belt

Thank you for your attention!