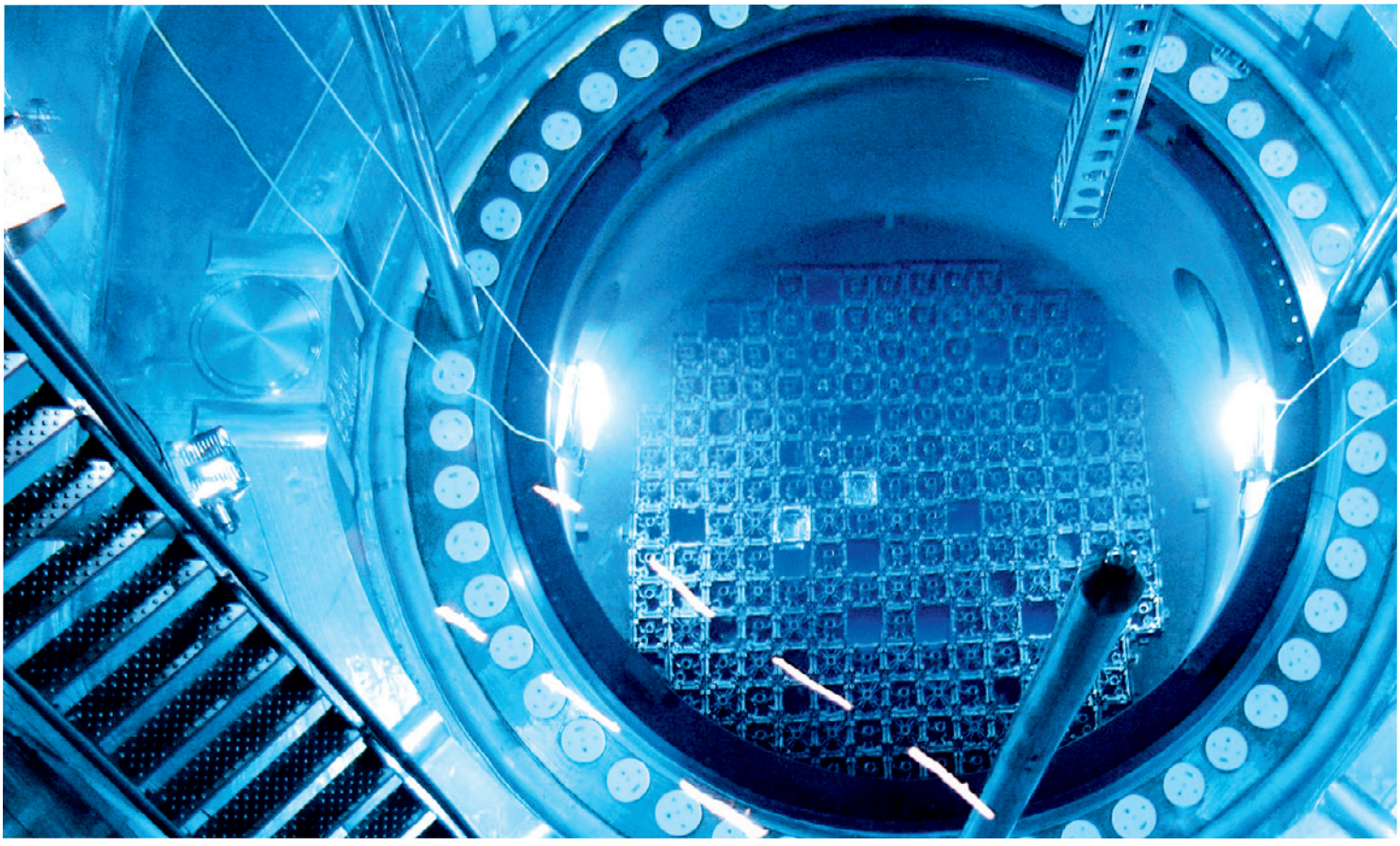
LINSEIS

THERMAL ANALYSIS

THERMAL ANALYSIS OF NUCLEAR MATERIALS

DIL
STA
LFA

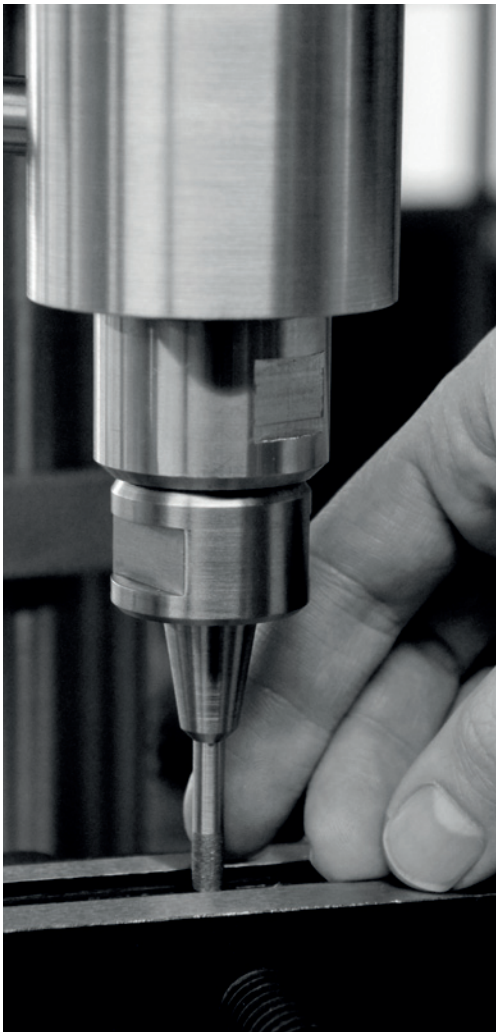


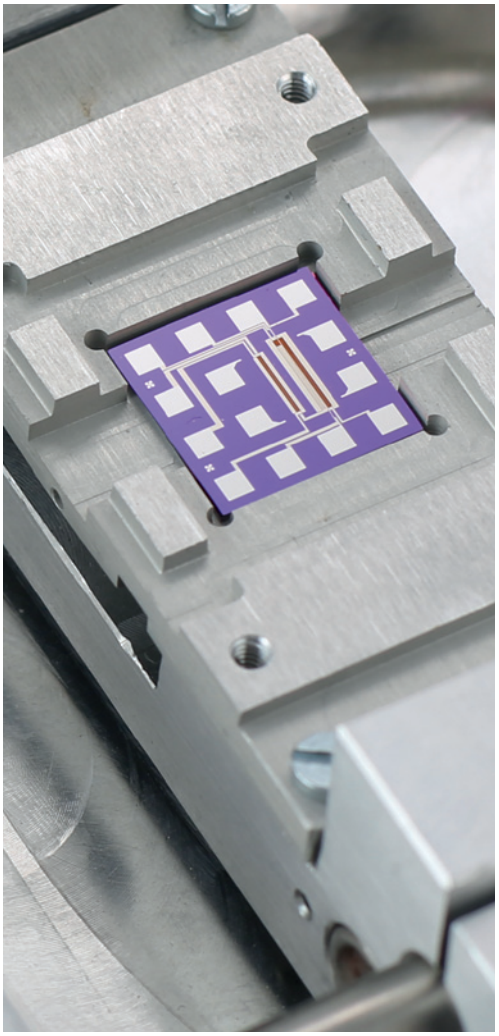
Since 1957 LINSEIS Corporation has been delivering outstanding service, know-how and leading innovative products in the field of thermal analysis and thermo-physical properties.

Customer satisfaction, innovation, flexibility and high quality are what LINSEIS represents. Thanks to these fundamentals our company enjoys an exceptional reputation among the leading scientific and industrial organizations. LINSEIS has been offering highly innovative benchmark products for many years.

The LINSEIS business unit of thermal analysis is involved in the complete range of thermo -analytical equipment for R&D as well as quality control. We support applications in sectors such as polymers, chemical industry, inorganic building materials and environmental analytics. In addition, thermo-physical properties of solids, liquids and melts can be analyzed.
LINSEIS provides technological leadership. We develop and manufacture thermo analytic and thermo-physical testing equipment to the highest standards and precision. Due to our innovative drive and precision, we are a leading manufacturer of thermal Analysis equipment.
The development of thermo-analytical testing machines requires significant research and a high degree of precision. LINSEIS Corp. invests in this research to the benefit of our customers.

Claus Linseis
Managing Director





German engineering

The strive for the best due diligence and accountability is part of our DNA. Our history is affected by German engineering and strict quality control.

Innovation

We want to deliver the latest and best technology for our customers. LINSEIS continues to innovate and enhance our existing thermal analyzers. Our goal is constantly develop new technologies to enable continued discovery in Science.

THERMAL ANALYSIS OF NUCLEAR MATERIALS

HISTORY

At the end of the 19th century, the famous scientists Pierre and Marie Curie (see Fig.2) discovered that the beam lines of uranium that were described by Henry Becquerel (see Fig.1) before are not just a magnetical or electronical effect but radioactivity.

Becquerel had found that several uranium salts that he had placed on a photo-plate in a dark chamber showed black lines on that plate in the absence of light which was an unknown effect to him. He assumed that there must be a kind of irradiation that was not part of the spectrum of visible light, similar to the x-rays (discovered by Wilhelm Conrad Röntgen shortly before) named these beams "uranium beams".

Pierre and Marie Curie were able to prove not only the existence of these beams but also that they were the direct result of the nuclear fission during their later research. They focused their whole scientific life on that field and won the Nobel prize for physics in 1903 together with Henry Becquerel. They also discovered new radioactive elements, named Polonium and Radium, where Polonium was named after the country Marie Curie was born at.

Once the effect of radioactivity was known, a lot of people were active in this field and many more elements were discovered. Also, the nature of irradiation and its impact on matter were discovered in many studies. Ernest Rutherford (see Fig.3) was able to classify the different types of irradiation, once they were described by Becquerel and Curie. He was the first one who categorized the three types of radioactive emission into alpha-, beta-, and gamma-irradiation.

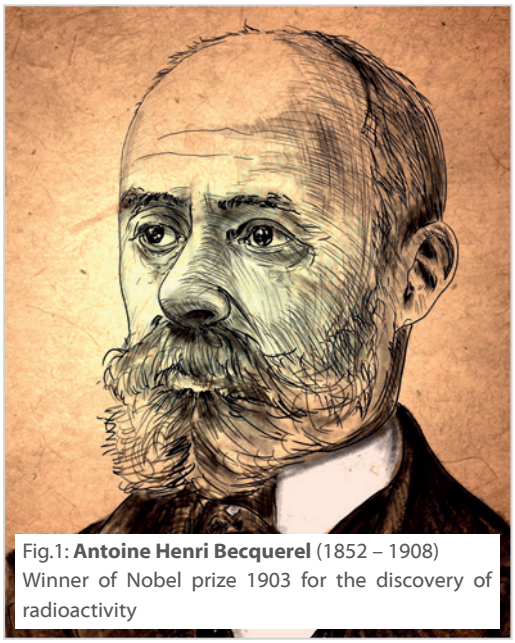


Fig.1: **Antoine Henri Becquerel** (1852 – 1908) Winner of Nobel prize 1903 for the discovery of radioactivity

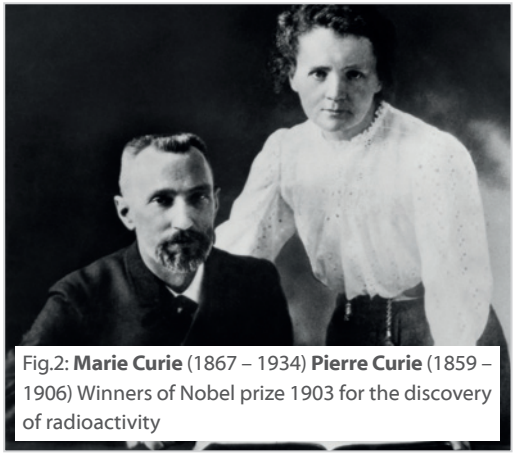


Fig.2: **Marie Curie** (1867 – 1934) **Pierre Curie** (1859 – 1906) Winners of Nobel prize 1903 for the discovery of radioactivity

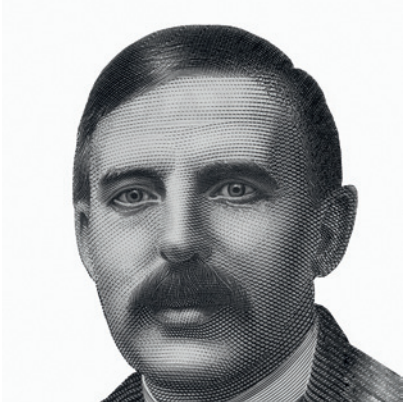


Fig.3: **Ernest Rutherford** (1871 – 1937) Winner of Nobel Prize for chemistry 1908 for the Rutherford atomic model

RADIOACTIVITY

Ernest Rutherford was the one who postulated an atomic model that could explain the behavior of matter scientists had observed so far in 1911. It was clear that there was a kind of elemental "building kit" consisting of different sorts of smallest particles, so-called atoms that were able to interact with each other, to form bigger agglomerations, so-called molecules.

He developed a model that described atoms as spherical particles that consist of positive charged protons, neutral neutrons and negative charged electrons. The protons and neutrons were also responsible for the mass of the atom as electrons almost had no mass. The mass containing protons and neutrons were located in the atomic core which was considerable small and the electrons were located in a hull with considerable big diameter (see Fig.4).

At present day we know that this elemental description of atoms is correct in general, besides the fact that the orbits for electrons are much more complex than Rutherford was postulating. The Rutherford model is still used at school to explain the fundamental setup of atoms and their nature.

But Rutherford was not only postulating the atomic model but also, as mentioned, was able to explain the radioactivity, Curie and Becquerel had discovered. When radioactivity was discovered, atoms were thought to be the smallest existing particles. It was not clear that they were able to decompose into smaller atoms by sending out radiation, energy and particles. However, the fact that they were sending out particles and radiation looked logical if they were considered to be structured in a way Rutherford had postulated (see Fig.5).

The three types of radiation that were known were from then on classified as alpha-radiation (particles are send out), beta-radiation (electrons are send out) and gamma-radiation (electromagnetic energy is send out). Later, the particle irradiation was separated in alpha-irradiation (alpha particles / He-cores) and neutron emission, while gamma-irradiation was separated into x-rays and y-rays depending on the wavelength.

We meanwhile know that radioactive radiation is caused by nuclear fission, either by statistic fission of radioactive materials or by chain re-

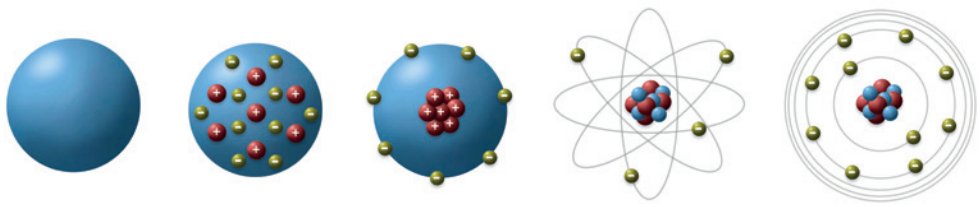


Fig.4: Development of the Rutherford atomic model: Assuming atoms to be spherical structures containing positive and negative particles he found that the negative charge carriers are located in the so-called atomic hull (later postulated as defined orbits by others) and the positive charge carriers and mass carrying particles must be located in the so called "core".

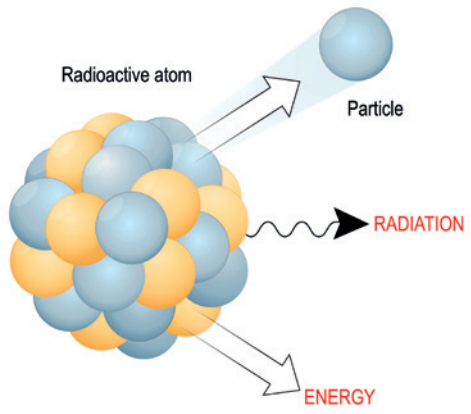


Fig.5: Radioavtive atoms undergo nuclear fission. The unstable atomic cores collapse into smaller cores by sending out particles, radiation and energy

action or fusion reaction. Atoms that have high atomic masses (heavier than lead and bismuth) are not stable and their cores are decomposing into smaller atoms by emitting radiation. These elements that undergo statistic fission are called radioactive elements. What kind of radiation they emit is depending on their atomic mass and nature of their core structure. The different kinds of radiation are shown in Fig.6. As can be see, the different types of radiation are potentially penetrating matter which makes it hard to control it once the radiation is released. And depending on the sort of radiation, it can transform non-radioactive atoms into radioactive matter.

If matter is exposed to radioactive radiation, it may change its structure by becoming radioactive itself. In case of life forms or humans it can have a devastating influence as radioactivity can't be sensed biologically however is very dangerous by mutating cells or even burn organic matter.

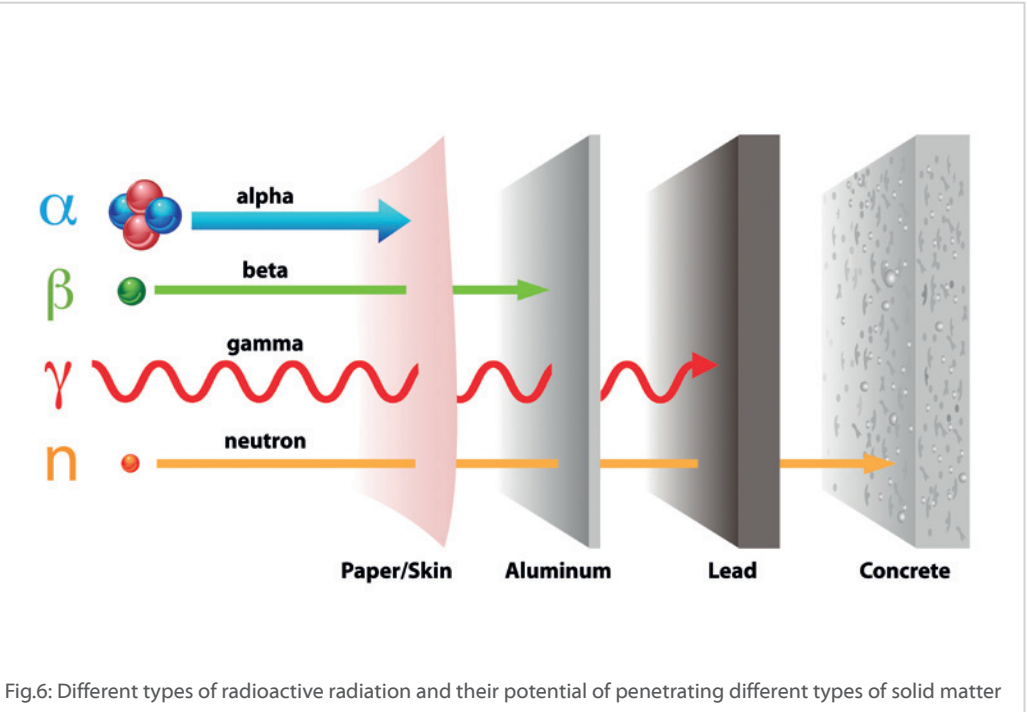


Fig.6: Different types of radioactive radiation and their potential of penetrating different types of solid matter

INDUSTRIAL USE OF RADIOACTIVITY

As radioactivity was known since the beginning of the 20th century and a lot of scientists were working on this interesting new field, it took until 1938 when Otto Hahn and coworkers finally discovered the nuclear fission and possibility of controlled nuclear fission.

In the following years, the second world war took place, leading to the fact that one of the first uses of this discovery was of military nature. But since the 1950s, nuclear energy is the most important energy source around the world. With its advantage of clean and cheap power supply, nuclear reactors were undergoing a continuous global improvement during the last 50 years. Meanwhile reactors of the 4th generation such as very high temperature reactors (VHTR) or sodium cooled fast reactors (MSR) are currently under development and will be the future for nuclear energy.

The general setup of a core reactor is shown in fig.7: A setup of so-called nuclear fuel rods is placed in a chamber (in most cases in a water bath), creating heat. The heated water is transferred to a second water loop that powers a steam turbine system and is transferred back through a condenser. The condenser is coupled to environmental water that is used for cooling. This cooling water is what can be seen as white steam that is release from the big cooling towers that are iconic for nuclear power plants.

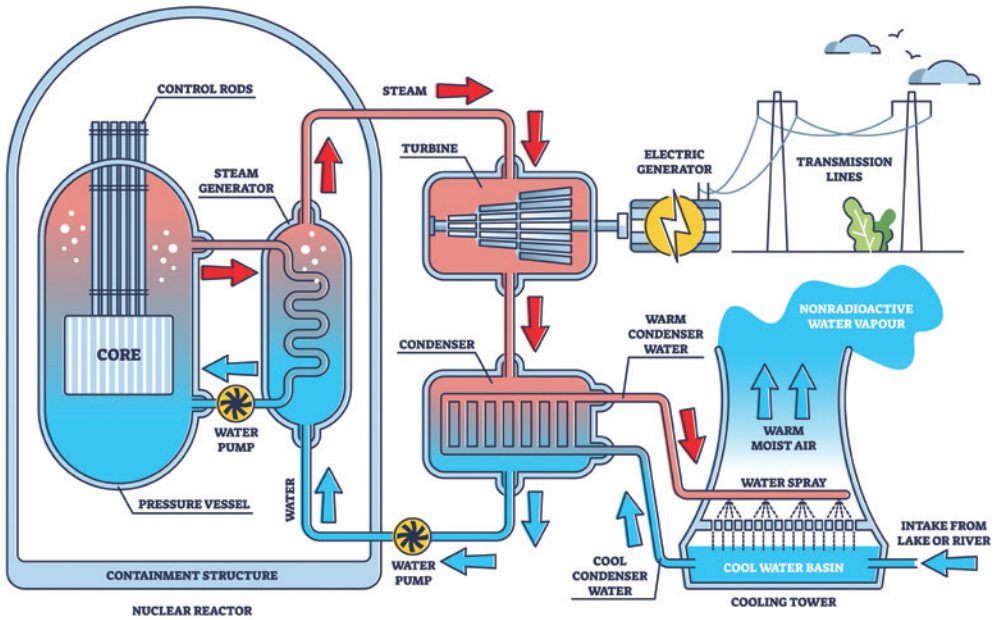
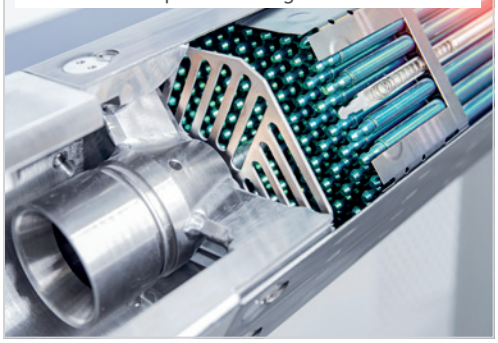


Fig.7: Typical setup of a nuclear reactor. Left: Core with nuclear fuel and two water loops; middle: turbine for power generation and condenser; right: cooling tower

NUCLEAR FUEL

The technical use of radioactivity is mainly based on the nuclear chain reaction, a concept where the fission of one radioactive core causes multiple fission events in neighbouring atoms by emitting neutrons. (see fig.8) Usually, uranium and its salts are used as neutron source. However, the natural uranium species are dominated by 98% of U238 which is not emitting much neutrons when undergoing fission. Therefore, the uranium U235 has to be accumulated first. This is a process where the 1% U235 species of natural uranium is separated in a complex process by gas centrifugation. The result is uranium with a much higher content of U235 that emits enough neutrons to start a chain reaction or a self-sustaining ongoing fission process. For nuclear reactors, a U235 content of at least 20 % is needed, while in weapon technique, the content has to be significantly higher. In a nuclear power plant, so-called fuel rods are made of accumulated uranium (see fig.9). These rods are positioned in array structures containing passive control rods and active reaction rods. The passive control rods consist of inactive material that stop the chain reaction by "catching" neutrons while the active rods are emitting neutrons and run the chain reaction cascade. When controlled properly, the reaction is in a stable condition and is self-sustaining, emitting constantly heat which creates steam for the turbine. Additionally, in most reactors, a mechanical robot system can exchange used active fuel rods and replace them by fresh ones. With that setup, the reactor can run permanently and create energy on demand, independent of any fossil fuels, wind or sunlight.

Fig.9: The nuclear fuel rods consist of Uranium filled pellets that are arranged in a stack (rod) and put into a matrix of multiple controlling and reaction rods.



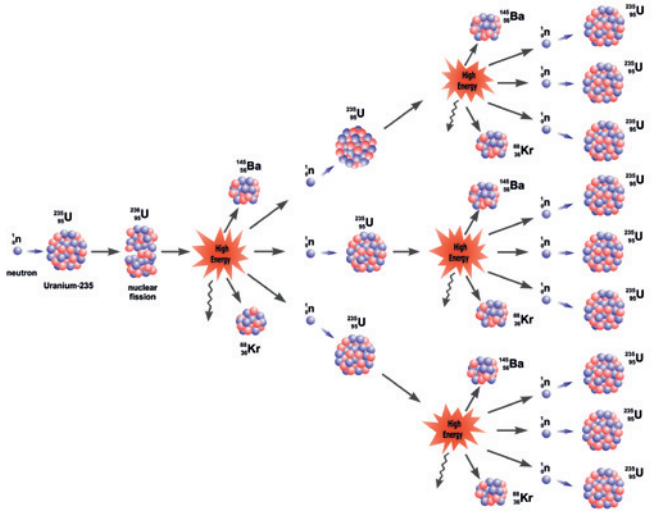


Fig.8: In most cases, U235 is used as power source. When hit by a neutron the core collapses and forms new species, releasing more neutrons that can react in a cascade with other U235 cores.

DRAWBACKS OF NUCLEAR ENERGY

When used, the nuclear fuel rods usually undergo a recycling process where the still usable U235 species are separated and used for new fuel rods. All the other elements that are created during the chain reaction (like Pu, Po…) are also separated and used for other purposes such as clinical applications or other industrial processes. For some of these isotopes, a nuclear chain reaction is the only source that can even create them. However, a lot of material is just radioactive dead matter that does not see any other use than being stored as nuclear waste. These waste materials are emitting a lot of radiation and are very dangerous and toxic to the environment, so they have to be stored somewhere where they are inaccessible and do not influence ground water, natural resources or life.

A proper place for that purpose is of course hard to find but still this is the only chance to get rid of atomic waste as there is no way to neutralize the radioactivity once the material is existing. Also, the nuclear reactors themselves have to be unmounted in a very long lasting and complex process once the reactor is abandoned, causing high cost and creating even more nuclear waste material.

Of course, besides the waste topic, there is also the risk of accidents and unwanted release of nuclear material into the environment. This, so-called greatest possible accident, happened a few times in the past, having devastating influence on life on earth in 1986 in Chernobyl and 2011 in Fukushima.

Fig.10: The residual amount of non-re-usable nuclear materials is nuclear waste and has to be safe stored for thousands of years.

RESEARCH

The nuclear power supply and industrial use of nuclear technology comes with a broad field of ongoing research. Not only the optimization of nuclear fuels and their recycling is a hot topic but also the work with radioactive samples for clinical research and therapy as well as further improvement for reactor safety and performance optimization. Scientists still are looking for storage and re-use technologies for nuclear wastes and also try to design nuclear fuel rods that produce only minimum amounts of toxic isotopes.

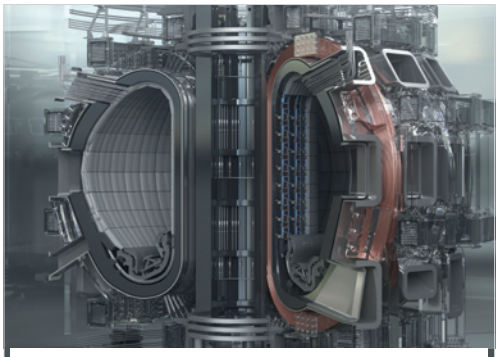


Fig.11: The future nuclear power plant will be most likely not a fission but a fusion reactor. A massive setup of magnets can keep the plasma beam of billion degree hot hydrogen within a field that allows to control the fusion reaction of hydrogen cores into helium, resulting in huge amounts of released energy and only very little radiation and no toxic isotopes.

Besides that, one of the biggest research projects is the development of fusion reactor technology that is promised to solve the worlds energy problems once it is available. The advantage of a fusion reactor would be an almost radiation-free energy generation that requires only small amounts of hydrogen to form helium in a fusion reaction.

THERMAL ANALYSIS IN NUCLEAR RESEARCH

Due to the research that is done in that field, there is a need of analytical equipment and especially also for instruments of thermal analysis. Of course, these special applications and safety requirements need a lot of modifications of the standard devices, which Linseis can do.

As nuclear radiation may interfere with the electronics, this has to be separated from the mechanical parts of the instruments and must be put outside the hot cell or glove box.

We did customizations of nearly every important instrument in thermal analysis that include the adaption for hot cell applications such as separation of electronics and control panels. Mainly dilatometers, thermo-balances as well as combined TG-DSC and also Laser Flash techniques were successfully transferred into a nuclear design by us in the recent past. Our experience in this special field makes Linseis become the worldwide leader in thermal analysis of nuclear materials as we are the most flexible player on that market.

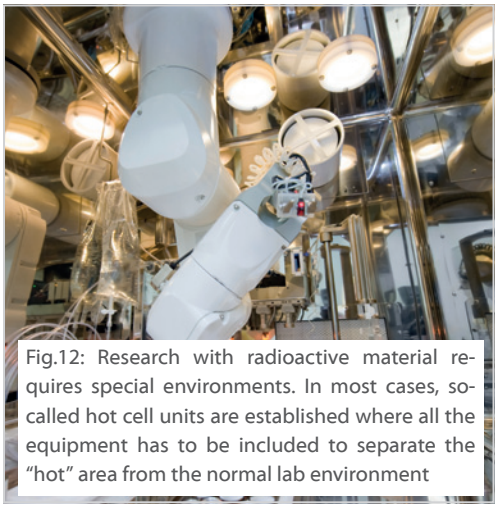


Fig.12: Research with radioactive material requires special environments. In most cases, so-called hot cell units are established where all the equipment has to be included to separate the "hot" area from the normal lab environment

Dilatometry

Dilatometry (DIL) is a technique where a dimension of a substance under negligible load is measured as a function of temperature while the substance is subjected to a controlled temperature program in specified atmosphere. In nuclear research, there are a lot of materials that have to withstand thermo-mechanical influences and therefore it is necessary to know their expansion and shrinkage behavior. Examples are hulls for nuclear fuel rods, reactor walls but also materials that are used in uranium accumulation.

TECHNICAL EXPANSION COEFFICIENT

The main value a dilatometer determines is the thermal- or technical expansion coefficient which characterizes the expansion of a material as a factor per degree Kelvin. I can be calculated as follows:

$$\alpha_{tech}(k) = \frac{1}{L_0} \quad \frac{\Delta L_k - \Delta L_0}{T_k - T_0} \qquad (k=1....n)$$

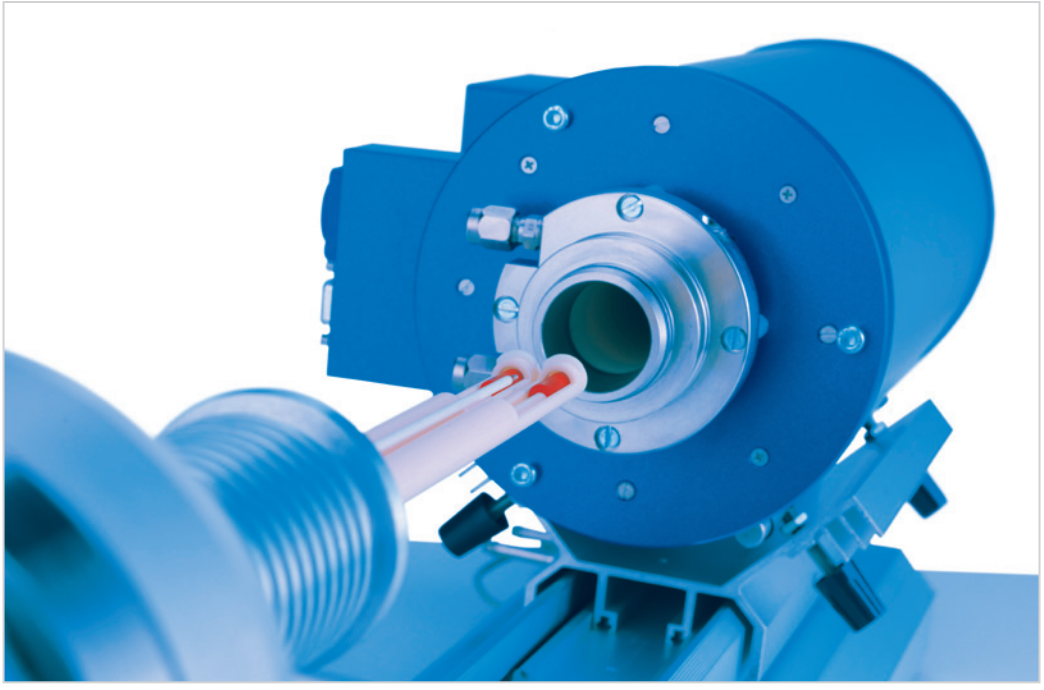
for every measured point k.

L_0 is the sample length at 20°C, ΔL_0 the change in length at 20°C (linear extrapolated out of the first data points), ΔL_k the according length change at the temperature Tk.

MEASURING THERMAL EXPANSION OF RADIOACTIVE SAMPLES

The standard instrument for measuring the thermal expansion coefficient (CTE), the dilatometer, detects the change in length of any sample by LVDT detector systems. For toxic and radioactive samples, it was necessary to separate electronics and detector. Beside this, the design was also changed to a more accessible setup for maintenance and mechanical changes under glovebox or fume hood.

Another method for CTE determination is the contact free optical dilatometer. It can be used with any atmosphere and no force is applied to the sample. For less x-ray emitting samples it can be a very useful instrument, however it can also be placed within a glovebox or fume hood.



TECHNICAL SPECIFICATIONS

	L 75 Horizontal	L75 Vertical	L75 Laser	L74 Optical
Temperature range	-180 up to 2000°C	-180 up to 2800°C	-180 up to 1000°C	-100 up to 2000°C
Atmospheres	Inert, oxidizing, reducing	Inert, oxidizing, reducing, vacuum	Inert, oxidizing, reducing, vacuum	Inert, oxidizing, reducing, vacuum
Resolution	1nm	1nm	0.3nm	1µm

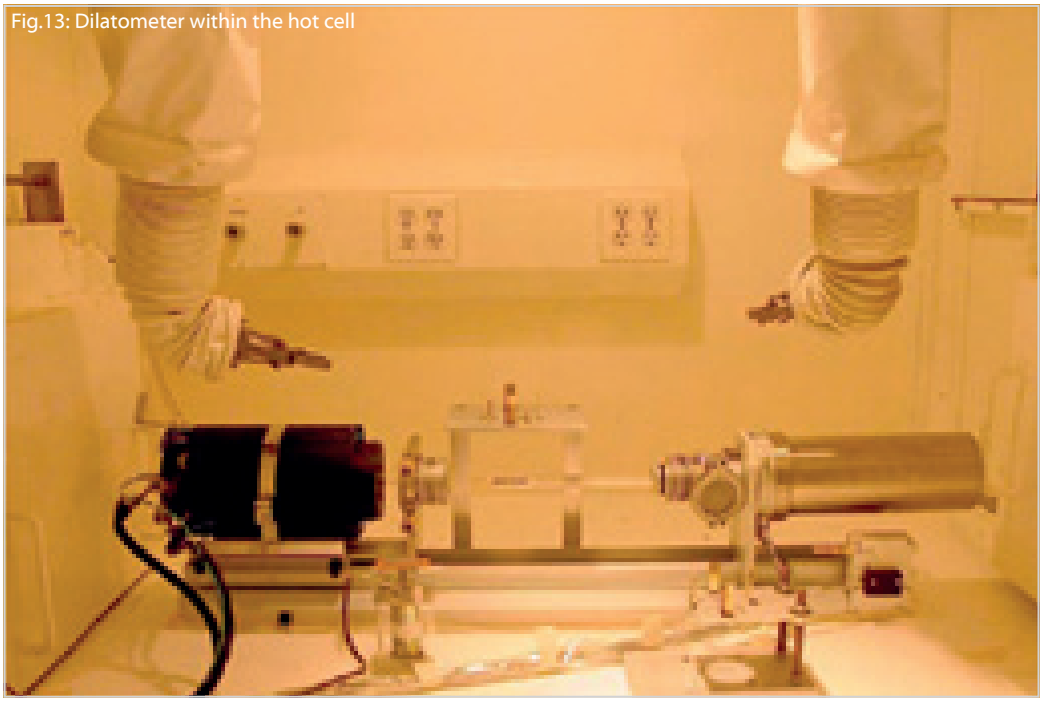
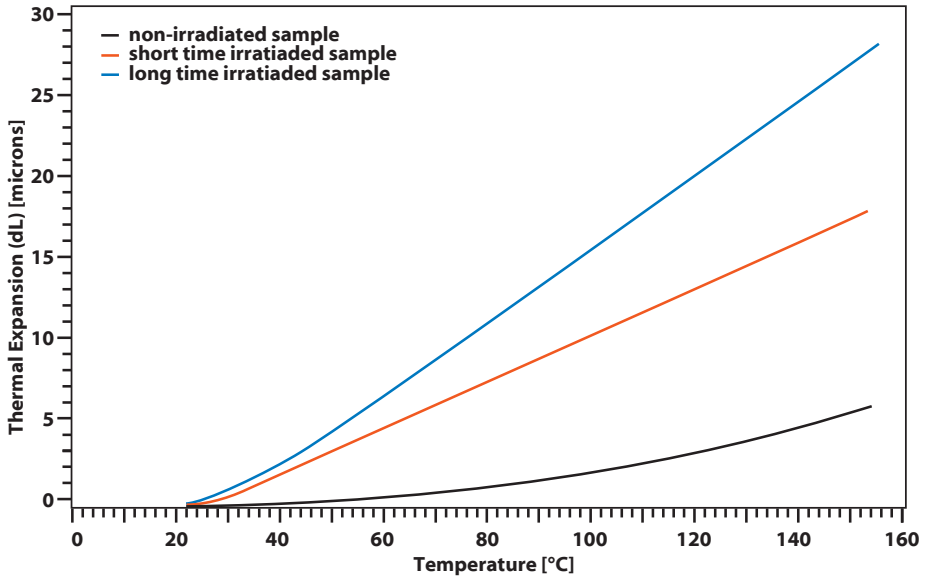


Fig.13: Dilatometer within the hot cell

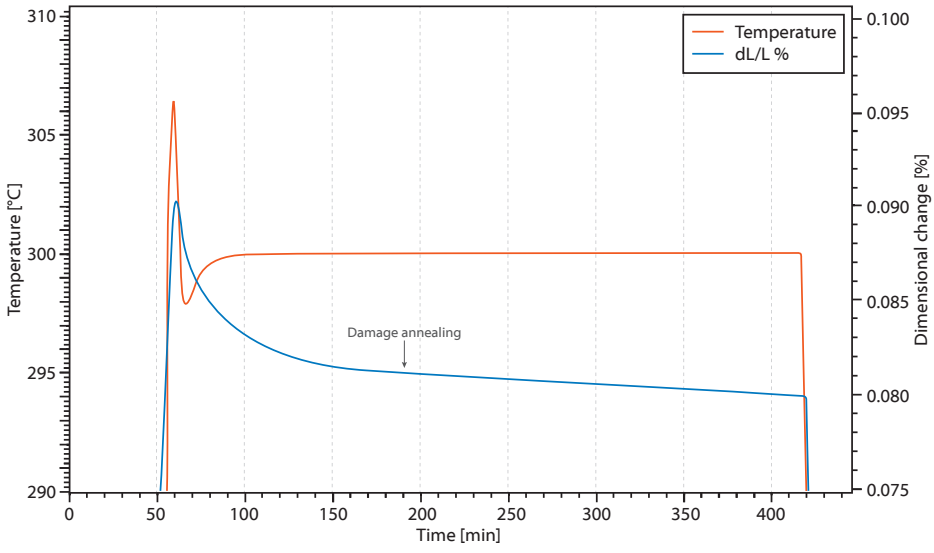
APPLICATIONS

Dilatometric investigation of proton irradiated material



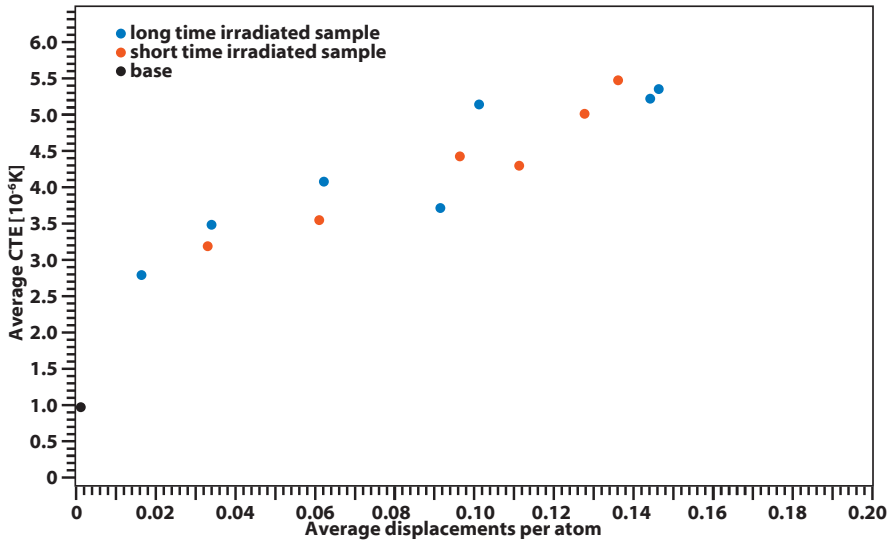
Samples of super-invar steel were irradiated by high power proton beams. The resulting materials were analyzed in a high precision two-rod Linseis dilatometer (L75 HD) in a special version, suitable for analysis of radioactive materials and operated in a hot cell (see Fig.13). The figure shows the bigger expansion coefficients of irradiated materials and a comparison with its non-irradiated state.
At temperatures higher than shown here, annealing was observed (see application below).

Annealing of irradiated samples



Dimensional change of irradiated samples during long time annealing at 300°C. Dimensional change was observed during 6 hours isothermal segment at 300°C. Shrinkage is caused by damage annealing induced by elevated temperatures.

Super-invar



Harold G. Kirk

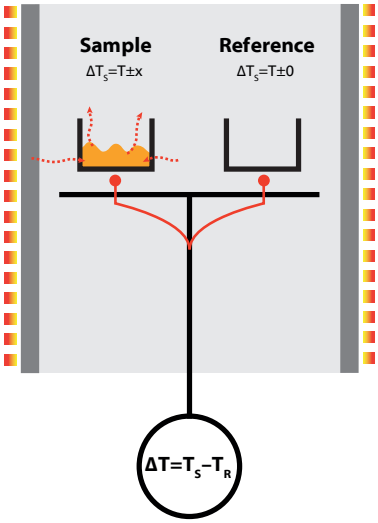
Coefficient of thermal expansion (CTE), shown as a function of the average displacement per atom for 2 differently irradiated samples and the corresponding non-irradiated sample. Irradiated materials show significantly bigger CTEs than non-irradiated materials.

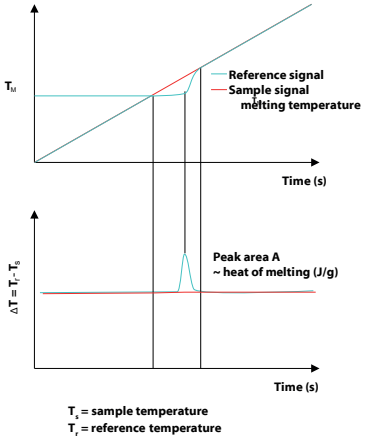
Simultaneous Thermal Analysis

Simultaneous TGA-DTA/DSC measures both, heat flow and weight change of a sample as a function of temperature or time under controlled atmosphere. Simultaneous measurement of these two material properties not only improves productivity but also simplifies interpretation of the results. The complimentary information obtained allows differentiation between endothermic and exothermic events which have no associated weight change (e.g., melting and crystallization) and those which involve a weight change (e.g., degradation).

DSC- True Heat Flow measurement

Quantitative DSC-signal





Differential Scanning Calorimetry (DSC)

"A technique in which the difference in energy input into a substance and a reference material is measured as a function of temperature, while the substance and reference material are subjected to a controlled temperature program."

Differential Signal

The differential signal is displayed as a baseline. Effects, for example the melting of a metal, can be observed as a peak. The area of the peak gives the amount of enthalpy and the direction of the peak indicates the direction of heat flux – endothermic (down) or exothermic (up).

Temperature vs. Time

During an effect like a reaction, decomposition or phase transition, a temperature difference (heat flux difference) between the sample and the reference crucible can be measured by means of a thermocouple.

MEASURABLE PROPERTIES

- Mass change in % and mg
- Rate controlled mass loss
- Evaluation of mass loss
- Residue mass evaluation
- Compositional analysis

- Enthalpy
- Endo- / Exo- thermic
- Phase transformation
- Melting point
- Glass point
- Crystallinity

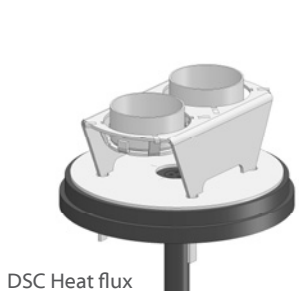
- Thermal stability
- Oxidation stability
- Purity
- Solidus / Liquidus relationship
- Product identification

SENSORS

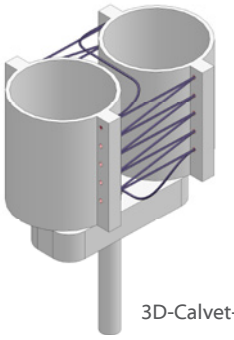
Linseis STA can be equipped with an unmatched amount of different user exchangeable TG-DSC, TG-DTA or TG sensors.

Each sensor is available with different thermo-couples to provide the highest sensitivity for the desired temperature range.

TG-DSC



DSC Heat flux



3D-Calvet-DSC sensor

0.12ml

0.12ml

Different crucibles available / broad variety

custom volume

- Al_2O_3
- Platinum
- Aluminium
- others

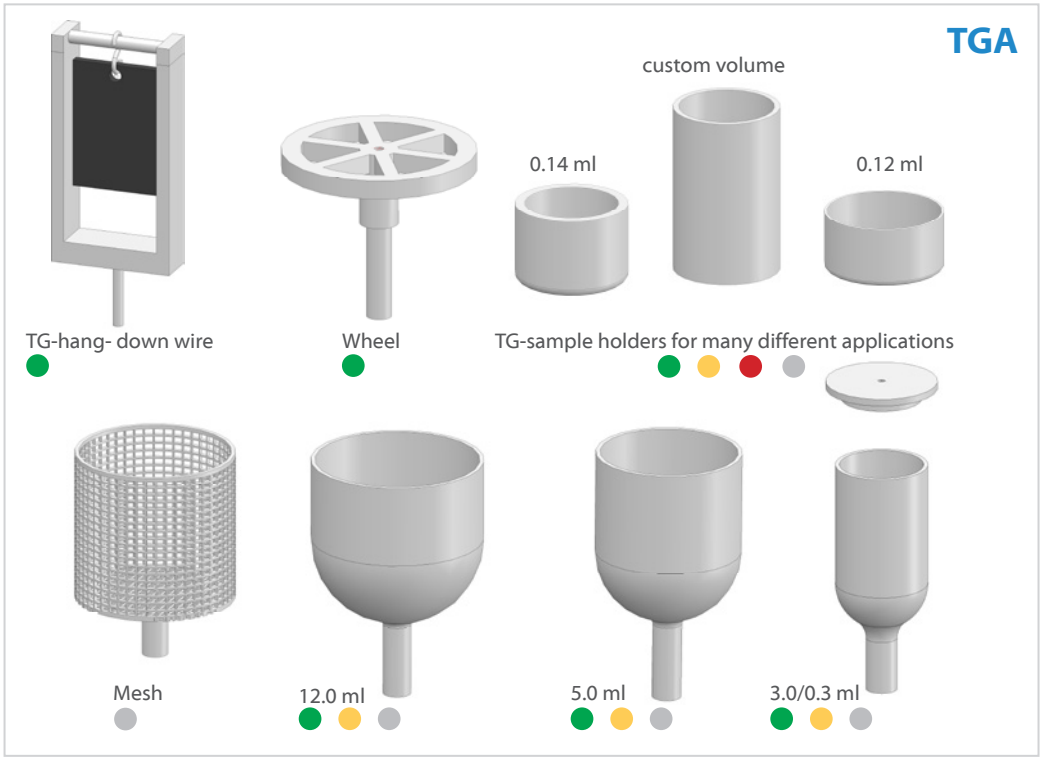
TG-DTA

DTA-sensor

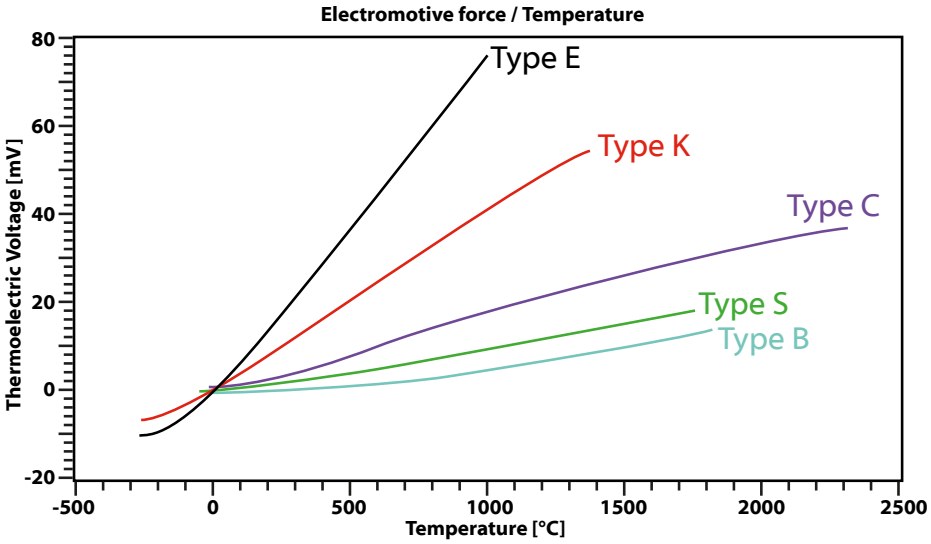
Cap

0.3ml or
custom volume

Crucible



Best possible sensitivity for every application



All sensors available with the thermocouples illustrated. LINSEIS sensor combinations cover the broadest temperature range in the market (-180°C up to 2400°C).

NUCLEAR VERSION OF STA

For toxic and radioactive samples, the STA instrument was splitted into two units. As it was necessary to separate elextronics and control unit from the measurement hardware, the Furnace and balance unit are one part that can be placed in a hot cell while the electronics are connected by special feed-throughs and are located outside. The samples can be loaded and unloades easily by robots or with gloves as the system as a top-loading balance unit allows easy access.

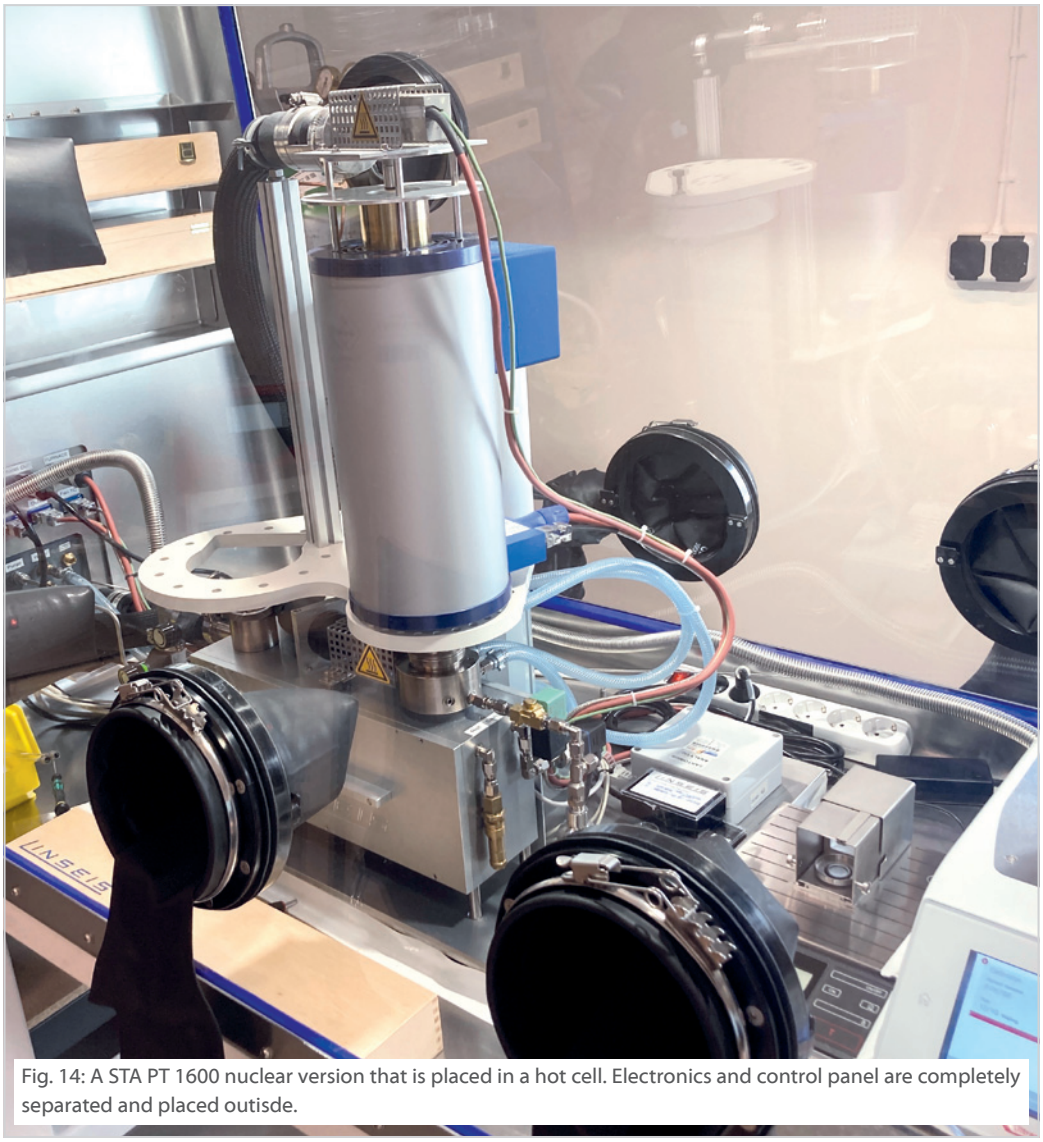


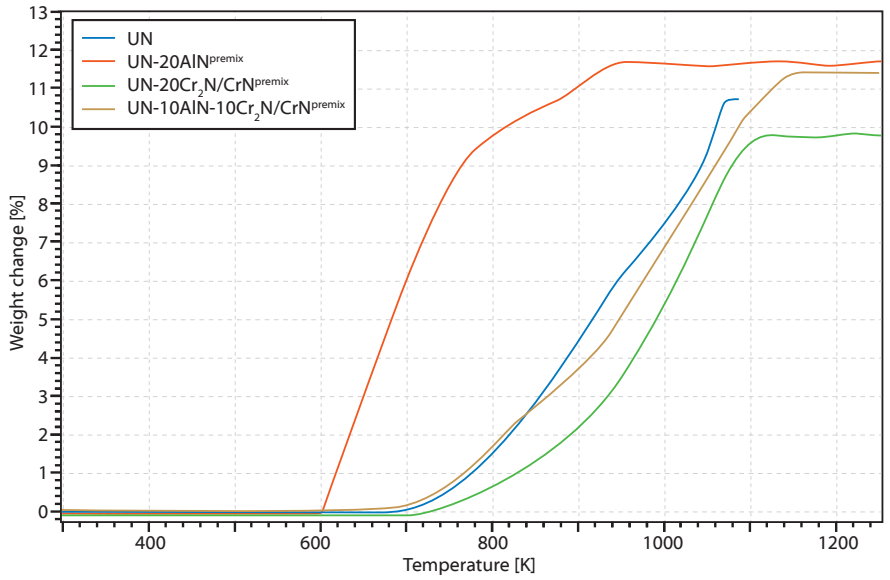
Fig. 14: A STA PT 1600 nuclear version that is placed in a hot cell. Electronics and control panel are completely separated and placed outisde.

SPECIFICATIONS

	STA PT 1600		
Temperature range	-150°C up to 2400°C (depending on furnace)		
Vacuum	10^{-5} mbar (depending on vacuum pump)		
Pressure	up to 5 bar (optional)		
Heating rate	0.01 up to 100K/min (depending on furnace)		
Temperature precision	0.01°C		
Sample robot	optional 42		
TG			
Resolution	0.025 µg	0.1 µg	0.1 µg
Sample weight	5 g	25 g	35 / 50 g
Measuring range	25 / 2500 mg	25 / 2500 mg	35000 mg
DSC			
DSC-sensors	E / K / S / B / C		
DSC resolution	0.3 / 0.4 / 1 / 1.2 µW		
Calorimetric sensitivity	approx. 4 / 6 / 17.6 / 22.5 µW		
DTA			
DTA-resolution	0.05 µV		
Sensitivity	1.5 µV/mW		
DTA-measuring ranges	250 / 2500 µV		

APPLICATIONS

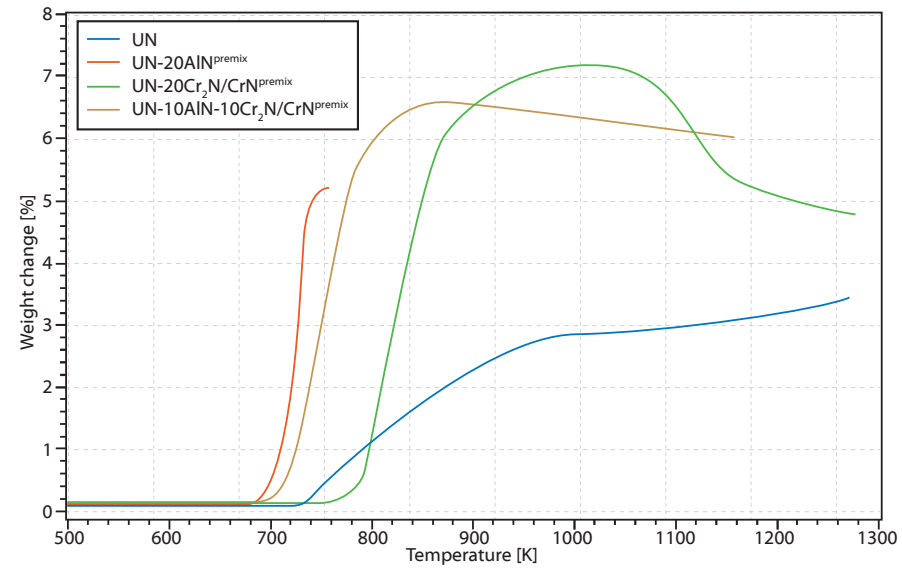
Uranium nitride advanced fuel- Oxidation resistance of coated and doped grains



Oxidation curves for UN and composite pellets in air

Uranium nitride can be considered as alternative accident tolerant fuel (ATF) for Uranium(IV) oxide (UO2) in light water reactors (LWR). Its drawback being its rapid oxidation in presence of steam or water in case of loss of cladding. Composites with other nitrides however may increase its stability.

A customized simultaneous thermal analyzer based on STA PT1600 with steam generator and mass spectrometer coupling was used inside a glove box in order to evaluate the oxidation and hydrolysis properties of Uranium nitride (UN) and some composites (composites with AlN or/and Cr2N/CrN) obtained by spark plasma sintering.



Weight gain curves for UN and composite samples in steam

UN and some composites were analyzed in a dry air stream of 50 cm3/min in a temperature range from room temperature up to 1273 K (heating rate 10 K/min). Weight increase due to oxidation was monitored. UN-AlN showed the lowest onset temperature of oxidation and lowest maximum oxidation temperature while UN-20Cr2N/CrN showed the highest temperatures.

UN and some composites were then analyzed in steam containing atmosphere obtained by feeding 0.015 ml/min water in an evaporator und purging the balance by 15 cm3/min argon resulting in a 1:1 mixture of H2O and Ar. Temperature was increased from room temperature up to 1273 K with a rate of 10 K/min. Weight increase due to hydrolysis was monitored. Once again, UN-AlN showed the lowest onset.

Laser Flash Analysis

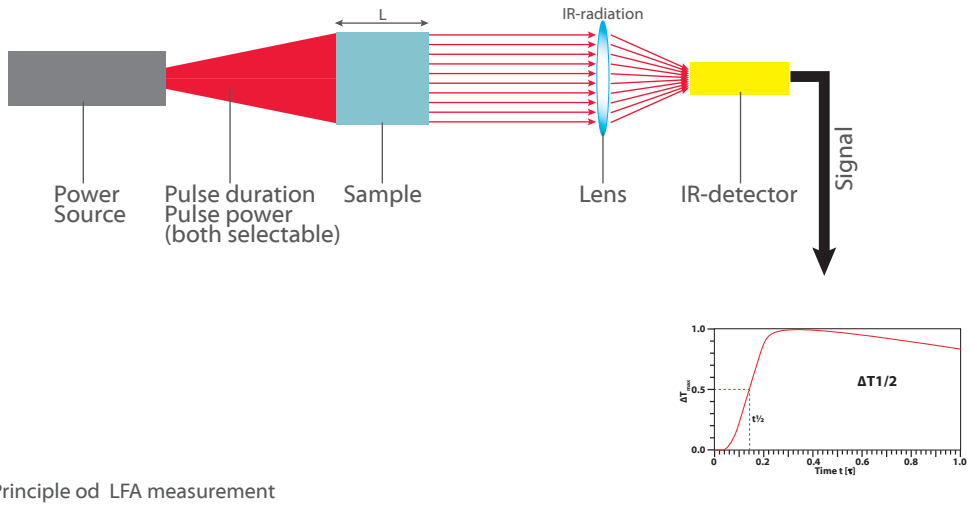
To determine the thermal conductivity, thermal diffusivity and specific heat, there are different methods available, depending on the desired temperature range, type of material and accuracy of the analysis. The most common and universal way to measure the thermal diffusivity is the well-known laser flash method (LFA). The sample is pulsed by a laser and an IR detector on the opposite side detects the time dependent temperature rise, resulting in the thermal diffusivity value. If density and specific heat are known, the thermal conductivity can be calculated. The LFA technique can also be modified and adjusted for hot-cell use, enabling the analysis of radioactive materials.

Standard Test Method for Thermal Diffusivity by the Flash Method

A small, thin disc specimen is subjected to a high intensity short duration radiant energy pulse. The energy of the pulse is absorbed on the front surface of the specimen and the resulting rear face temperature rise is recorded. The thermal diffusivity value is calculated from the specimen thickness and the time required for the rear face temperature rise to reach certain percentages of its maximum value.

Out of density and Cp the thermal conductivity can be calculated using the following formula:

$$\lambda(T) = a(T) \cdot c_p(T) \cdot \rho(T)$$



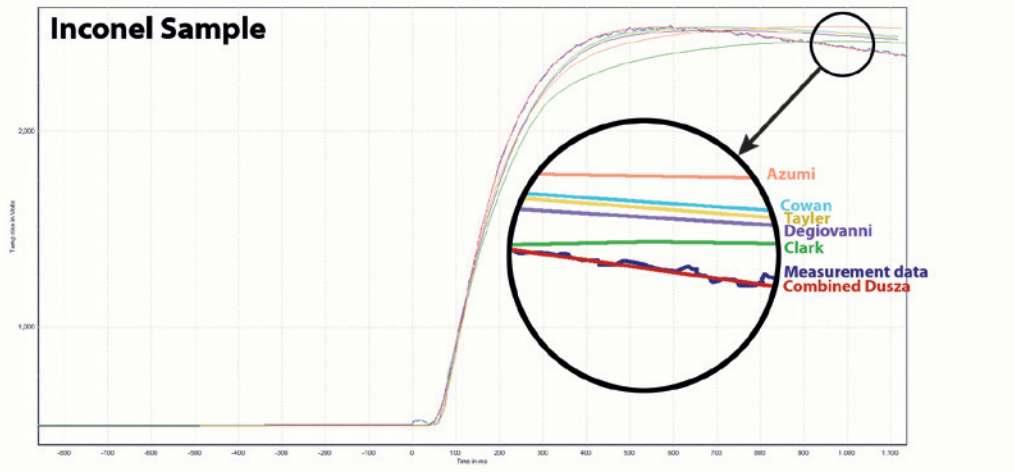
Principle od LFA measurement

Calculation of thermal diffusivity

- Determine the baseline and maximum rise to give the temperature difference, ΔT_{max}
- Determine the time required from the initiation of the pulse for the rear face temperature to reach $\Delta T_{½}$. This is the half time, $t_{½}$.
- Calculate the thermal diffusivity, a, from the specimen thickness, L squared and the half time $t_{½}$, as follows:

$$\alpha = 0.13879\ L^2/t_{½}$$

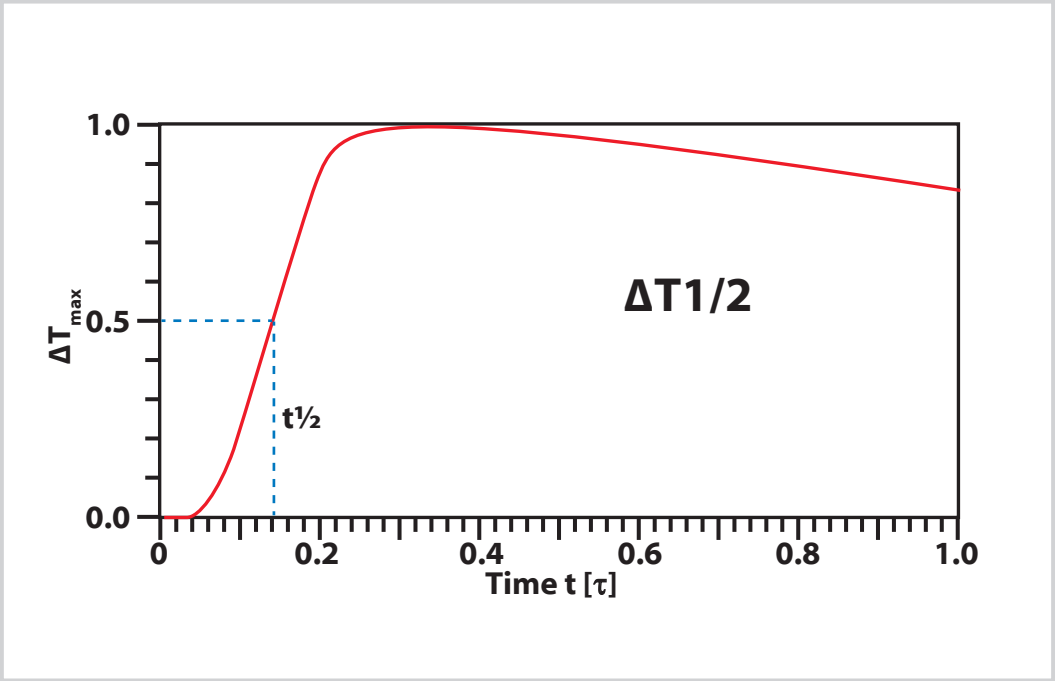
Combined solution of the simultaneous heat loss and finite pulse corrections with the laser flash method



Inconel Sample
Model Comparison-Demonstrating superior performance of the combined model versus classic models of: Azumi, Clark, Cowan, Degiovanni and Tayler

Conclusion

The combined model method with nonlinear parameter estimation has been proven for more than 100 samples. In all cases it worked reliably and its results gave the correct adiabatic, finite pulse, and/or heat loss corrected values. The two main advantages of the method are that no operator choice between the different models and correction is necessary, and the fit can be checked by plotting the model curve.



For Special setup for radioactive or toxic samples

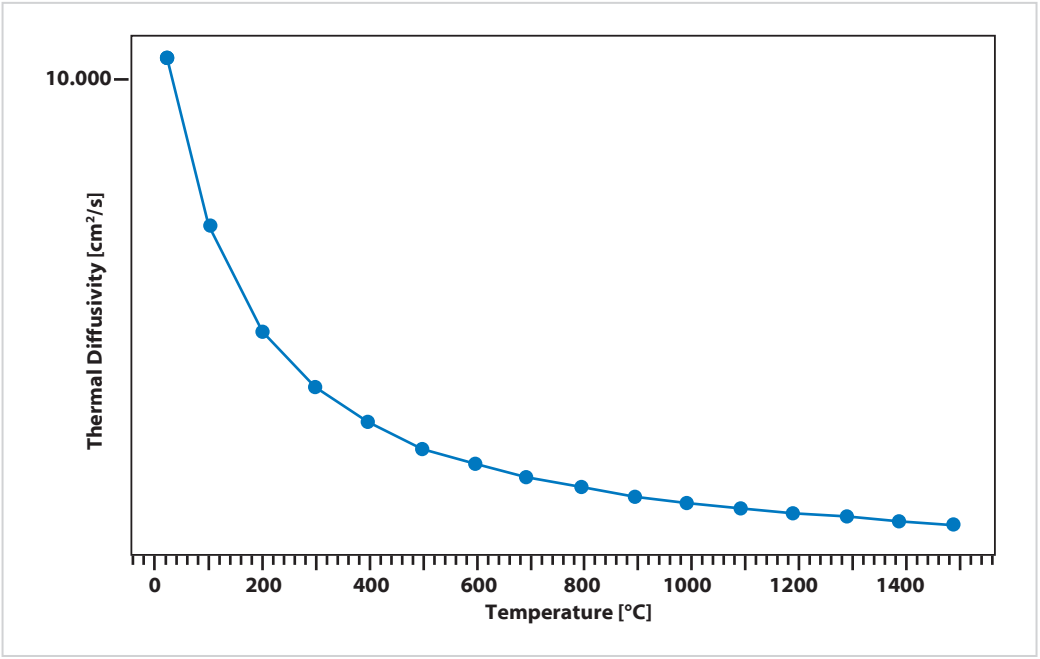
- Measurement unit separated from control electronics and laser
- Laser connected by fibre glass optical cable
- Measurement unit can be placed in hood or glovebox
- Maintenance, operation and setup possible in glovebox

TECHNICAL SPECIFICATIONS

	LFA 500	LFA 1000	LFA 1000 HT
Sample dimensions	ø 10 / 12.7 / 25.4 mm, 0.1 to 6 mm thick □ 10 / 20 mm; 0.1 up to 6mm thick	ø 3 / 6 /10 / 12.7 / 25.4 mm □ 10x10 / 20x20 mm	
Samples	solids, liquids, powders. pastes	solids, liquids, powders. pastes	solids, liquids, powders. pastes
Sample robot	up to 6 samples	up to 6 samples	up to 3 samples
Vacuum	depends on model up to 10^{-4}mbar		
Atmosphere	inert, oxidizing or reducing	inert, oxidizing, reducing or vacuum	
Measuring range Thermal Diffusivity	0.01 up to 1000 mm^2/s	0.01 up to 1000 mm^2/s	0.01 up to 1000 mm^2/s
Measuring range Thermal Conductivity	0.1 to 2000 W/(m·K)	0.1 to 2000 W/(m·K)	0.1 to 2000 W/(m·K)
Pulse source	Flash lamp	Nd:YAG Laser	Nd:YAG Laser
Pulse energy	10/15 J/pulse	25 J/pulse	25 J/pulse
Pulse energy & pulse duration adjustment	yes	yes	yes
Pulse length adjustment	software adjustable	software adjustable	software adjustable
Sensor type	InSb / MCT	InSb / MCT	InSb / MCT
Furnace model	**IR-furnace** RT up to 500°C RT up to 1000°C RT up to 1250°C **Cryo-Furnace** -125 up to 600°C	**Resistance heater** RT up to 1250°C RT up to 1600°C	**Graphite** RT up to 2000°C RT up to 2400°C RT up to 2800°C **Tungsten** RT up to 2400°C

APPLICATIONS

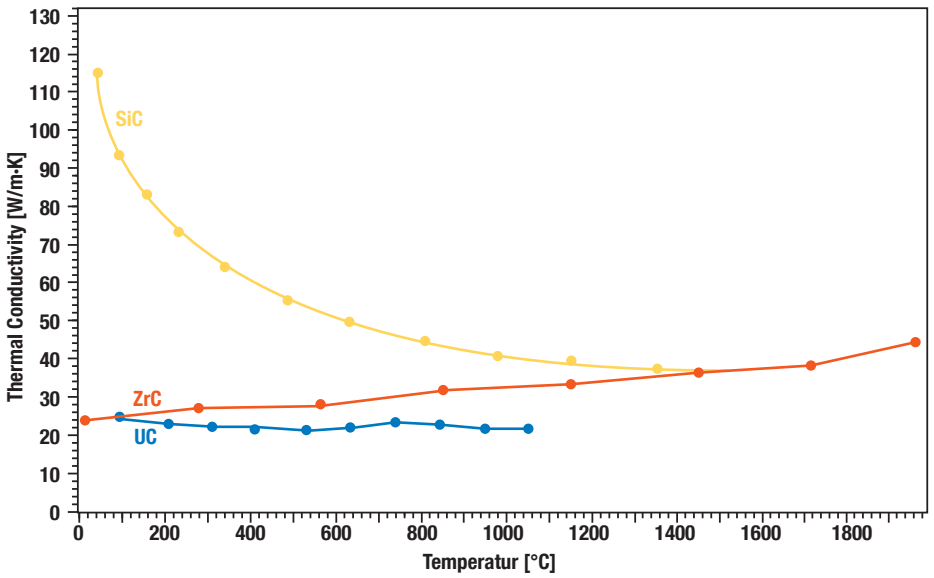
Graphite standard



The curve shows the thermal diffusivity data of a graphite standard from NIST that was measured with a special LFA with fibre-optical connected laser and separated electronics. The results are matching with the literature values and accuracy and power of the laser are completely identical with the standard instrument.

Graphite is one of the most important materials in reactor construction and due to its high thermal conductivity and temperature stability it offers various purposes it can be used for.

Thermal Conductivity Of Carbides



Different types of carbides were measured by LFA to determine the thermal conductivity. Uranium carbide was compared to similar Zirconium carbide and classic silicon carbide. As a result, the uranium carbide showed a considerable low value of around 25 W/mK, while zirconium carbide shows an increasing trend that has an electronic dominant character, whereas the SiC shows a more or less common decrease shape of its thermal conductivity curve.

LINSEIS GmbH Germany
Vielitzerstr. 43
95100 Selb
Tel.: (+49) 9287 880 0
E-mail: info@linseis.de

LINSEIS Inc. USA
109 North Gold Drive
Robbinsville, NJ 08691
Tel.: (+1) 609 223 2070
E-mail: info@linseis.de

LINSEIS China
Kaige Scientific Park 2653 Hunan Road
201315 Shanghai
Tel.: (+86) 61 90 12 03
Tel.: (+86) 50 55 06 42
E-mail: info@linseis.com.cn

LINSEIS Poland
ul. Dabrowskiego 1
05-800 Pruszków
Tel.: (+48) 692 773 795
E-mail: info@linseis.de

www.linseis.com

Products: DIL, TG, STA, DSC, HDSC, DTA, TMA, MS/FTIR, In-Situ EGA, Laser Flash, Seebeck Effect, Thin Film Analyzer, Hall-Effect
Services: Service Lab, Calibration Service

04/22

LINSEIS