



WITZENMANN
managing flexibility

NUCLEAR APPLICATIONS



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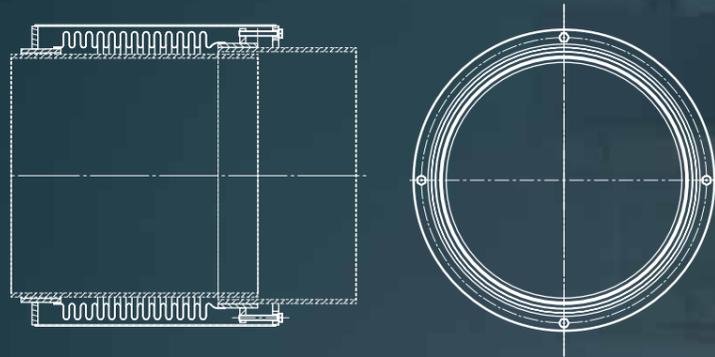
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1 STROKE, 100 YEAR LIFESPAN, 5000 PAGE SPECIFICATION

Hydra expansion joints for the final storage of highly radioactive waste.

Special characteristics: Extreme lifespan of > 100 years as well complete documentation and testing in accordance with 44 customer specifications.

Plant: Areva Customer: ACE-Endel



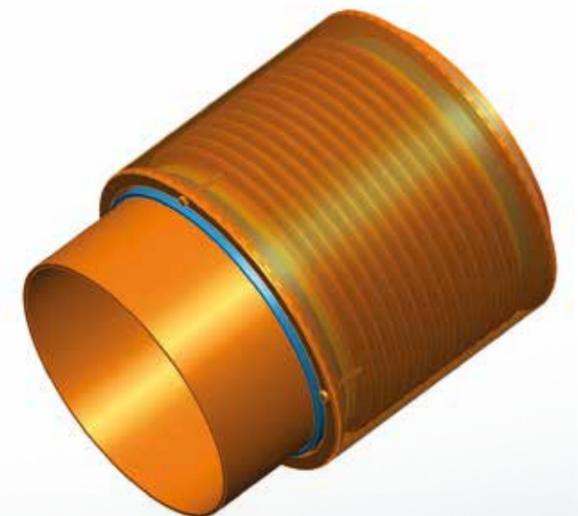
Highly radioactive waste generated during reprocessing of spent combustion elements and other contaminated material are consistently stored in interim or final storage facilities for decay. The secure and extremely long-term storage of this material is an important task for humanity. For that reason there are extreme requirements applying to the technical construction elements used in this field.

The case

Spent combustion elements or radioactive waste are inserted into a hard glass matrix for interim and final storage based on the state-of-the-art in technology. The melting into borosilicate glass is done as rough-grained granulate is heated up to approximately 250°C by radioactive radiation. This is placed in around 1-metre high stainless steel containers. These are then stacked on top of one another inside 330 stainless steel tubes each 17 metres high. The tubes stand vertically in the room and are only fixed above and below by massive foundations. In this way it is possible to continuously cool the steel tubes through natural convection in the area without technical resources. During the hundreds of years of storage the radioactivity slowly fades and thus the internal cylinder packages cool down slowly. This leads to changes in length of the external cover, which must be compensated for, as the entire length of the tubes cannot change.

The requirement

The challenge lay in the field of application and the associated comprehensive specifications and approvals prescribed by the extensive regulations of the nuclear industry and the required lifespan of > 100 years! This includes recording and excluding all conceivable risks, which meant extremely high product quality requirements.

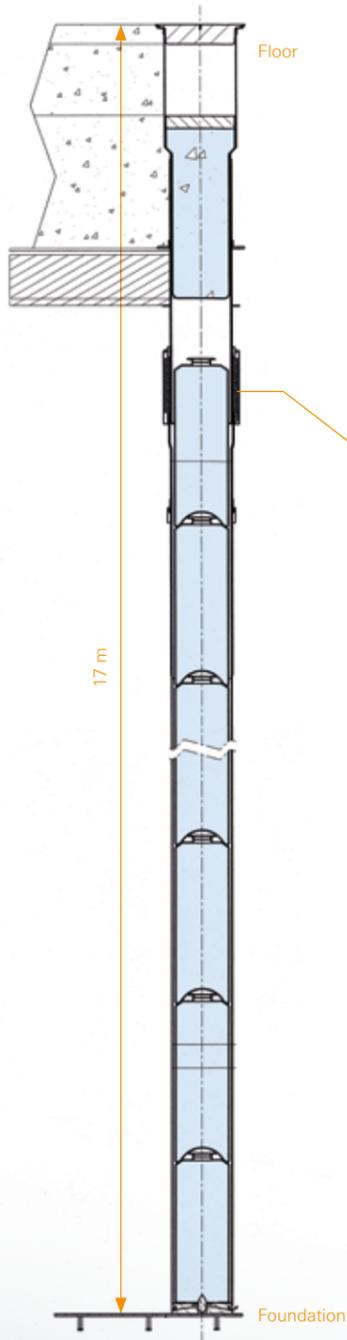


HYDRA® EXPANSION JOINTS FOR THE FINAL STORAGE OF HIGHLY RADIOACTIVE WASTE

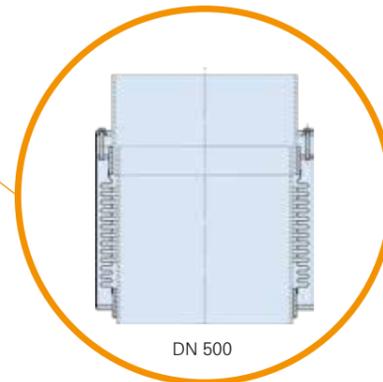
4000 PAGE SPECIFICATION

Example extract of testing scope for the nuclear industry (Part I)

Application



Technical data	
Type	DN 500, PN 1
Material	1.4571
Design temperature	235 °C
Movement absorption	160 mm
Movement cycles	designed for: 50,000 – real: 1! cycle



The stainless steel tubes with the expansion joints stand vertically in the room and are only fixed above and below by massive foundations.

The expansion joint is used to absorb the calculated length change of the steel cylinder from cooling down as well as the compensation for installation tolerances or other movements. Although according to the requirements profile only one movement cycle needed to be made (the slow cooling), it was designed for a long lifespan and tested to safely cover all foreseeable eventualities (earthquake, shifts, etc.).

The "small" series: 330 Hydra expansion joints for the final storage

Over a period of 12 months (6 months of production and 6 months of calculations, creation of production documents as well as testing and approvals from the customer and AREVA) 330 expansion joints were manufactured for ACE Endel and delivered just in time; always when a storage section was appropriately prepared. In the process, the entire production period was monitored by the customer.



The clean bellows (above) and the last production step - the welding of the external protective cover (right).



In total more than 40 visual inspections, tests and monitorings occur before, during and after the manufacture of each individual component. These will be comprehensively documented - in this case there were approximately 5000 DIN A4 pages. Unlike other industrial application fields, all documents must be kept available for 30 years for retrospective testing etc.

Below is an example of how time-consuming and elaborate the monitoring and testing of each production detail is. Ranging from the materials used to the shock-monitored transport box. It makes clear what a comprehensive testing area a company must have to be able to meet the enormous requirements of the nuclear industry.



Standard tests before production

- Refractory lining
- Check on the existence of all approved documents
- Check of manufacturing prerequisites (ISO 9001; KTA, AD2000-HP0; -W0)
- Review (external) of welder qualification
 - Relevant customer regulations
 - DIN ISO
 - ASME (Section 3 and Section 8)
- Individual additional certification of the particular customer as well as through the nuclear oversight authority
- Creation of the PCD (pre-check documents)
 - For the production sequence – in particular the welding processes – instructions must be created by Witzemann, which will be checked and approved by the customer in advance. They include all work and test steps including the required and verified staff qualifications. In addition the customer defines here which examinations or production steps it will be present at to supervise. Production can only begin once the VPU has been created and approved.
- Testing of all authorised resources



INHOUSE TESTS FOR MAXIMUM FUNCTIONAL SAFETY

Example extract of testing scope for the nuclear industry (Part II)

Tests in Witzemann's own test area

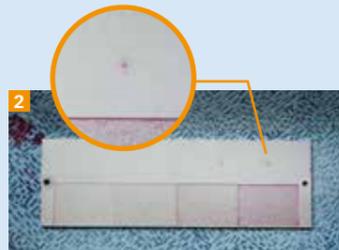
- Material (bellows material certificates):
 - Chemical purity
 - Surface purity/condition with scanning electron microscope
 - Tensile test of a material sample at room temperature
 - High-temperature tensile test (possible up to 900 °C)
 - Intercrystalline corrosion test
 - Identification testing of the materials using X-ray fluorescence
 - Material certificates check and comparison with the respective approvals

Tests during welding

- Spectroscopic testing of the welding consumables
 - Identification testing
- 100% testing of every welding seam
 - Surface crack testing (red/white – UV fluorescing test)
 - Helium leak test
 - X-ray testing in isolated X-ray room
 - Visual checks
 - Tests of the welding consumables (according to approval, chemical composition,...)

Surface crack detection test

Reference sample



1 On the prepared sample (left) special ink will be used with varying surface roughness and notches. Also on the welding seam of the expansion joint (right).

2 After the application time the part will be cleaned. Remaining colour intensity (analogous to the right sample area) requires reprocessing.

3 Final cleaning

Finished component



The test shows that the welding seam on the expansion joint has no surface cracks!

INHOUSE TESTS

Example extract of testing scope for the nuclear industry (Part III)



Pressure and leakproof testing in special liquid bath.



After all tests, monitorings and checks during production, the finished construction elements are ready to be thoroughly cleaned once again (osmotic water) before they are packed in special transport boxes.

Component tests (non-destructive)

- Leak testing
- Pressure testing
- Purity check
 - Chloride test
 - Halide test
 - Ferrite test

Component tests (destructive)

- Tensile tests
- Lifespan test (up to 800 °C temperature depending on the application)
- Burst pressure test

Comprehensive testing and documentation

All these tests can also be fully performed in the presence of customers and the nuclear oversight authorities. For example, every welding process will be carried out in the presence of others and documented.

All results will be comprehensively documented (mostly in two languages). Prior to production there will be a check on the welder and the process again to ensure all required qualifications and certificates exist.

HYDRA[®] EXPANSION JOINTS-DESIGN FOR ITER*

* International Thermonuclear Experimental Reactor
ITER (Latin): the path



Photo: www.iter.org

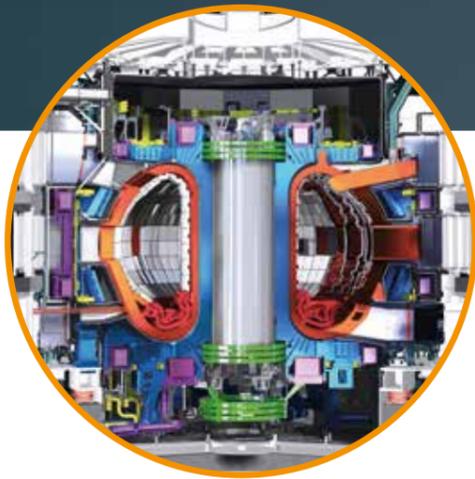
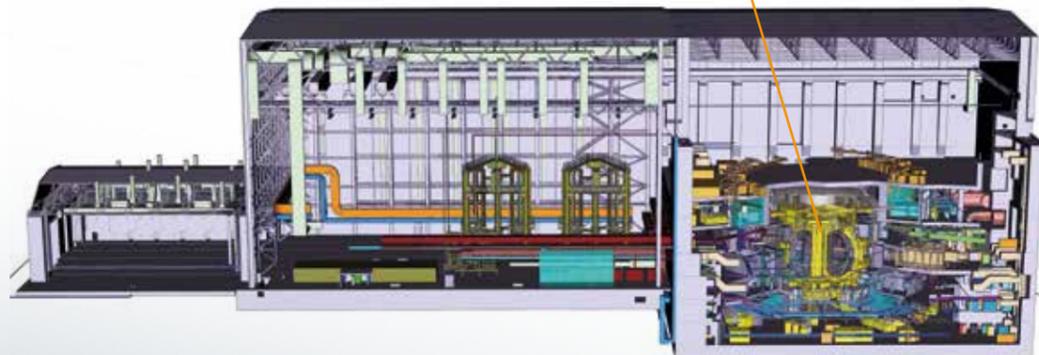


Illustration (2): www.iter.org



ITER is a core fusion reactor that has been under construction since 2007. It is an international research project aimed at generating power from fusion energy. The goal is to achieve burning of the plasma over 400 seconds - then the process is considered stable.

This should bring about a 10-fold increase in power compared to conventional nuclear fission. This corresponds to a fusion output of around 500 MW. The first trial run of the test system is scheduled for 2025, directly at the nuclear research centre at Cadarache in the south of France.

In nuclear fusion, an electrically charged particle beam, which is accelerated by magnets, comes into contact with plasma. This consists mainly of deuterium, an enriched hydrogen. The particle beam heats up the plasma until the fusion temperature is reached. Then the exothermic process runs independently, without additional energy being supplied.

DESIGN OF THE EXPANSION JOINTS IN ACCORDANCE WITH THE RCC-MRX REGULATIONS

The task

Construction, calculation and production of bellows for the High Voltage Bushing (HVB). The HVB Bellows are part of the Heating Neutral Beams (HNBs) of ITER. The bellows are placed between the Beam Source Vessel (BSV) and the High Voltage Bushing (HVB).

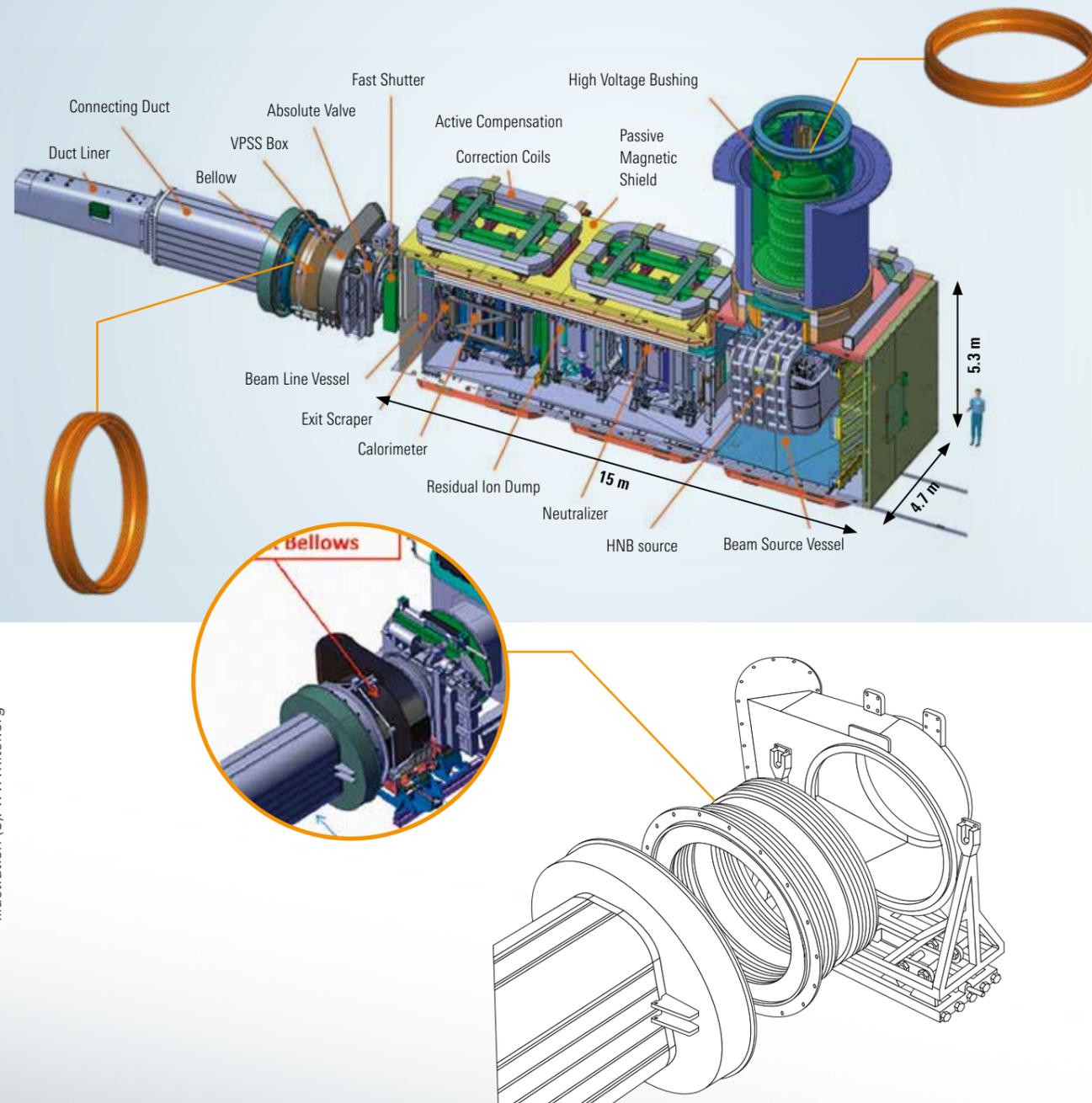


Illustration (3): www.iter.org

THE RCC-MRX REGULATIONS

The distinctive feature

For research reactors extreme design definitions apply for all components. These cover as broad a safety corridor as possible, as the practical behaviour of the individual processes is still not 100% known.

For that reason there is a calculation regulation for every individual structural element, created by the French oversight authority for nuclear systems. These were specified and strengthened again in respect of research reactors (-MRx).

These RCC-MRx regulations should guarantee the highest possible design and later functional safety. Among other things, they define the calculation and expansion joint design approach.

The RCC-MRx code has two ways for component verifications:

1. **Design by Analysis**
(Sec. III Subsection B RB/RC/RD 3200)
2. **Design by Rules**
(RB/RC/RD 3300-3900)

Design by Rules can be used only by some selected components and consider their characteristic features.

Design by Analysis can be used for every component but gives only general stress evaluation criteria for static and fatigue damages. With respect to the special mechanical and fatigue behavior of bellows, the way of design by rules was selected.

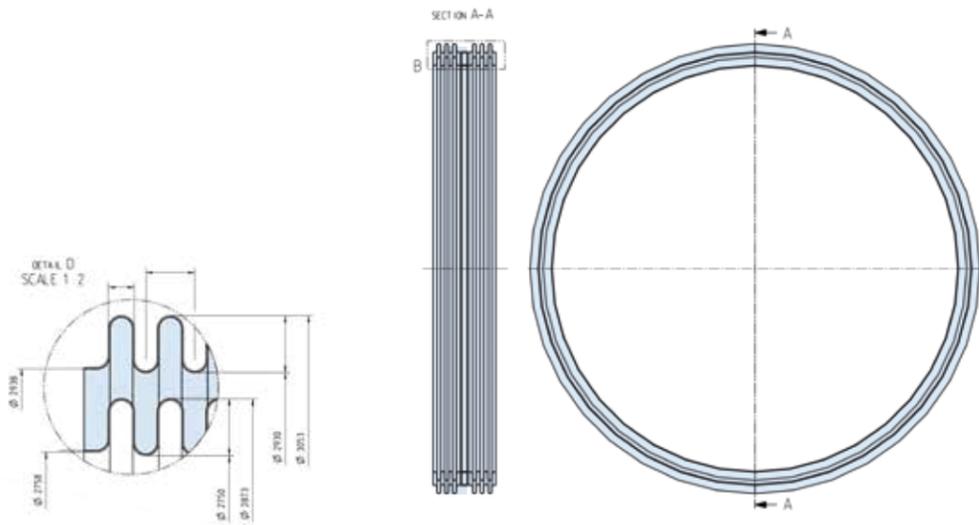


THE BELLOWS-IN-BELLOWS SOLUTION

The design

For the construction and design, alongside the technical requirement, the fact that once built this bellows can almost never again be dismantled was decisive. "No one comes there again!" The background of this statement is that radioactivity is generated during the fusion. The bellows can come into direct contact with this fusion material. Although this radiation "only" has a half-life of approx. 10 years. But even this comparatively very low half-life would mean that if there was a problem in this area it would be 10 years after shutting down the reactor before the damaged expansion joint could be replaced - an economically unjustifiable timespan.

Witzenmann developed a bellows-in-bellows solution for this application. With an internal and external bellows - almost structurally identical down to the particular diameter. This solution guarantees maximum long-term operational safety. As both bellows are designed on the basis of the RCC-MRx operating data. Each of the expansion joints thus fulfils the requirements for itself. Thanks to the bellows sheathing the plant then also remains secure and functional in the unlikely case of an internal bellows failing. The expansion joints were designed with single-walled bellows and as universal expansion joints (two bellows each, connected with a central tube segment). In this way the expansion joint can compensate for major movements in the axial and radial direction.

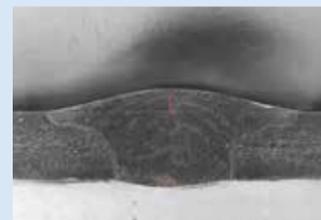
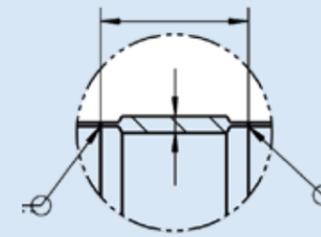
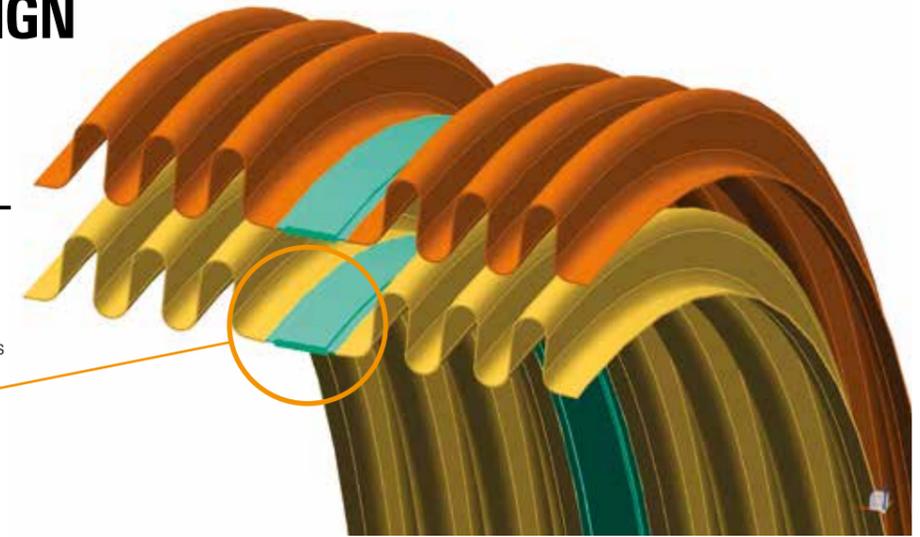


The internal and external expansion joints are then joined with one another and welded to a component using a blunt seam. Of course comprehensive production and testing documentation must also be created here throughout the entire process. As with all production processes for nuclear plants, there is also a sequential monitoring of individual production steps directly on site in the Witzenmann plant through customer experts as well as experts from the French nuclear consortium.

SINGLE-WALLED BELLOWS DESIGN

For 100 % verifiable production quality

- Single-walled bellows design is a prerequisite for blunt weld seams



Blunt seam welds under the scanning electron microscope

Improved quality verification through single-walled, blunt seamed bellows

In nuclear power plant construction, the design of the expansion joints with single-walled bellows is a typical demand. This is also true in the RCC-MRx regulations. This deliberately dispenses with the greater flexibility of multi-layer bellows - however the focus is on 100% verifiable production quality.

Single-walled or multi-walled bellows are usually welded to the respective connecting pieces with a fillet weld. The multiple layers make it impossible to verify definitively that the individual layers have been effectively welded through. With single-walled blunt weld seams, this can only be definitively established by means of through-steel X-ray testing. In general blunt seams are welded when high seam loads occur.

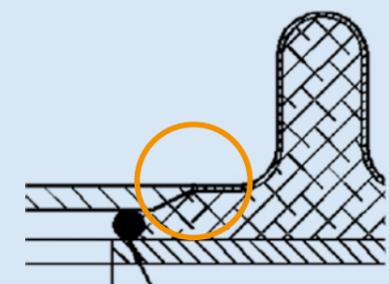
Multiple test series (UP welding, TIG welding, MAG welding) were run to filter out the most suitable process in combination with the widest range of resources and additives.

- Different welding powders (DW)
- Materials with various delta ferrite content (hot crack inclination in the welding seam)
- Creating ideal edge conditions (little edge offset, plate thickness difference, etc.)
- Use of ceramic bath supports for through-welding

All calculated parameters must later be verified with tests on the component.

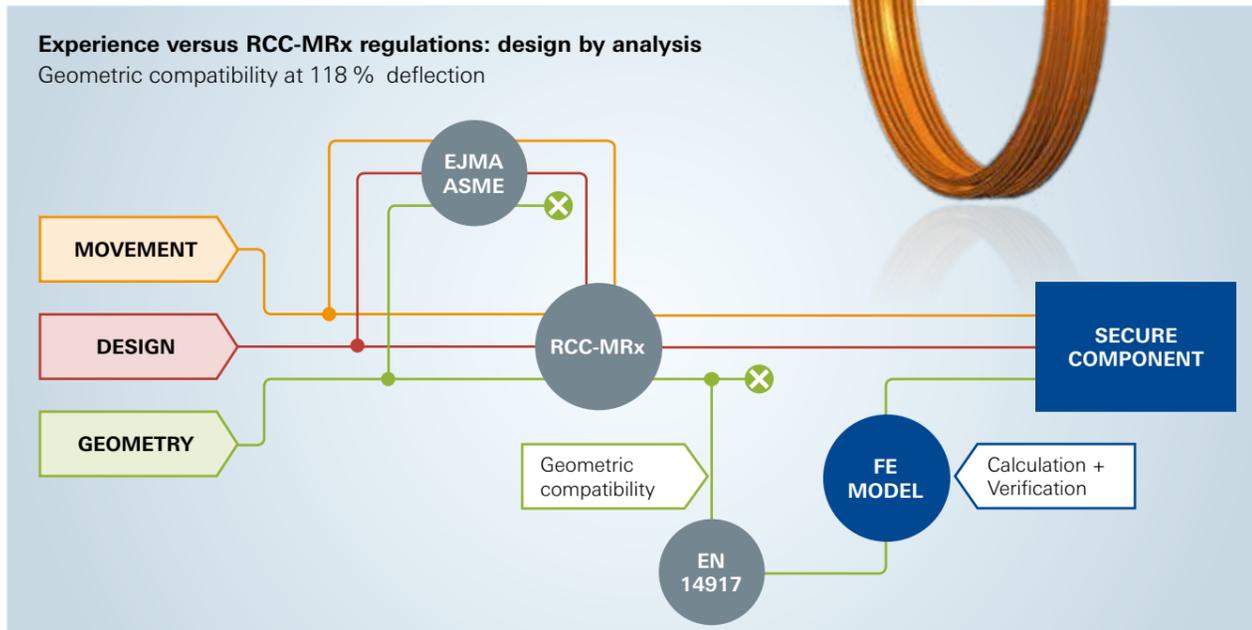
In particular with respect to:

- Spring rates
- Designed load cycle numbers
- Pressure stability



GEOMETRIC COMPATIBILITY WITH DOUBLE BELLOWS

Safety information through 1 : 1 FE simulation



Due to the specified construction lengths the single-walled design of the bellows as well as the required movements to be designed for, the Witzmann engineers, on the basis of their experience, expected a critical limit situation when the bellows were fully utilised. One of the restrictive parameters is the geometric compatibility. This point is dealt with in EN 14917, but not in RCC-MRx. However in this case it is of fundamental safety significance. Even in EN 14917 this is only dealt with mathematically in a rough way. It is a simplified consideration, with corresponding safety reserves, based on an individual bellows. The complex motions of a double bellows construction, such as the current design, are not included in this however.

Deliberate testing beyond the RCC-MRx regulations

Due to these safety-critical requirements, the Witzmann engineers carried out and logged analytical calculations in bellows limit behaviour in respect of geometric compatibility on the basis of EN 14917.

In total 30 different load cases were verified and calculated for each bellows. In four cases with the internal bellows (diameter 2758 mm) an overload of 10 % was detected (in total 110 %) and with the external bellows (diameter 2938 mm) an overload of 18 % was detected (in total 118 %). To achieve certainty about whether this calculated 118% would be critical in the case of the bellows being deflected, a 1:1 FE simulation of the movements was created for each scenario of this analytic excess. With the result: 3 mm distance of the corrugations from one another at maximum load of 118%. Proof of the safety of the double bellows construction in respect of geometric compatibility has thus been provided. Mechanical damage, even when the bellows is at maximum utilisation, has thus been excluded. An essential prerequisite for long-term operational safety.

SAFETY IN THE LIMIT RANGE

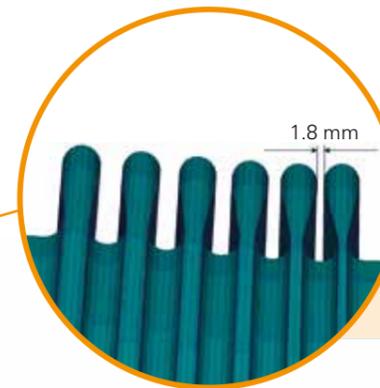
Testing beyond the RCC-MRx regulations

Geometric compatibility

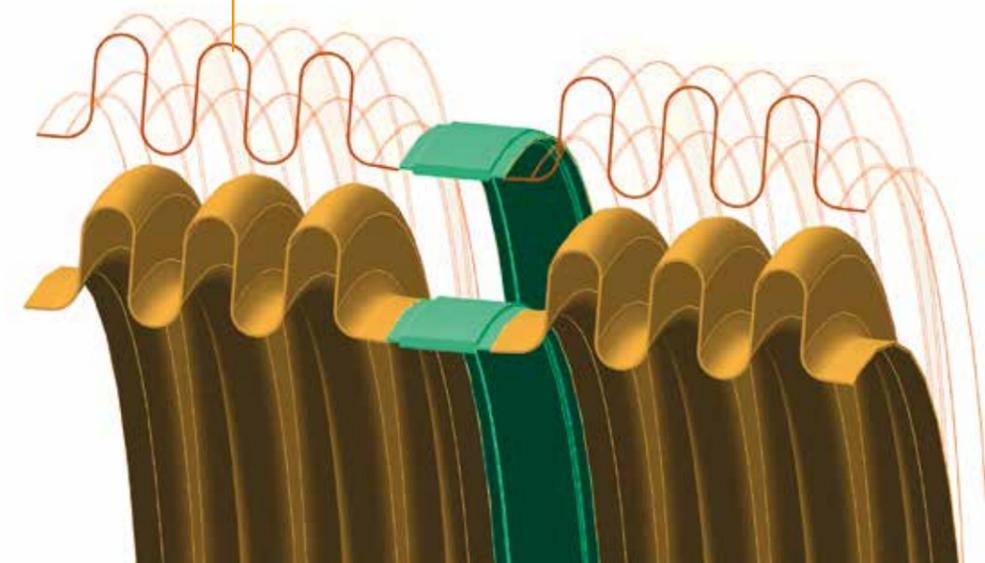
Bellows are designed in such a way that the individual corrugations do not touch during the largest deflection of the bellows. In extreme cases the bellows may be loaded or deflected beyond the calculated 100%. Then within the geometric design the so-called geometric compatibility is to be tested to determine whether in extreme cases the individual corrugations touch and thus go to "block".

If so, this can lead to plastic deformation of individual bellows corrugations, and thus to functional impairment. Local overstress of the individual bellows corrugations occurs, which can lead to temporary material fatigue and breakage of the bellows.

■ **With a double bellows**
the movement sequence of the corrugations to one another is completely different than with a simple bellows. This has significant effects on geometric compatibility.



Corrugation Distance
= Measured Distance - 2*0.5 Wall Thickness
 $\varnothing 3.3 \text{ mm} - (2 \cdot 0.75 \text{ mm}) = 1.8 \text{ mm}$



FLAMANVILLE 3/ FRANCE

49° 32' 14" N,
1° 52' 57" W

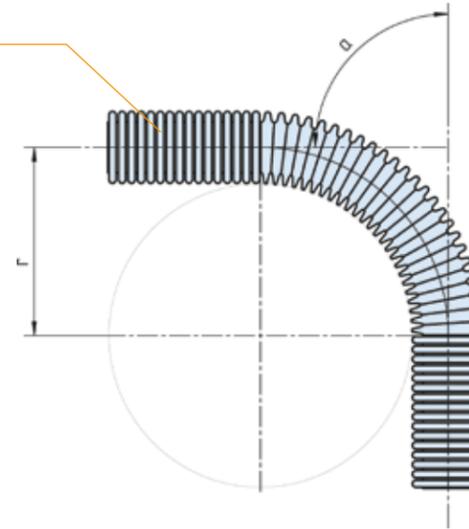


Photo: @EDF Médiathèque, Alexis Morin / Antoine Soubigou, tous droits réservés.



Flamanville 3 is an EPR (European pressurised water reactor) reactor and is currently being built on the French Atlantic coast. It should join the grid in 2018. The nuclear company Areva estimates the accident risk with the EPR at ten times lower than with older generations. In this reactor type, flexible HYDRA® components are used in various fields of application.

■ **In the bending test**
the required
lifespan of the metal
hoses was verified



Application 1: Annularly corrugated hoses

Changes in radioactivity in the primary circuit are recorded by various systems. The data cables that carry this measurement data must be protected from external disruptive influences (e.g. EMC – electromagnetic compatibility – or from mechanical influences) by a protective cover.

Metal tubes made from Mu-metal

Flexible tubes made from Mu-metal were planned for this application (μ -metal/permalloy). Mu-metal is a magnetically soft nickel-iron alloy that is used to screen low-frequency magnetic fields.

Magnifer from Mu-metal

Due to use in the nuclear industry, the comprehensive regulations and tests in the nuclear industry also apply in this case. Thus detailed manufacturer - meaning Witzemann - process testing (PT) must take place. This includes examination of the material among other things. Bending and crushing tests, pressure tests, testing of weldability, changes in material characteristics after the deformation including the procurement situation of the metal were relevant criteria for the use of the planned material.

Parallel examinations of related materials in the Witzemann testing laboratory showed that the material magnifer is partly superior to the originally anticipated Mu-metal. On the basis of this expert opinion - complemented with additional customer tests - the operator EDF switched to the new material for this application.



Under the scanning electron microscope, microsections of different materials (Mu-metal, magnifer and 1.4571) provide information about their changed microstructure after processing.

APPLICATION 1: ANNULARLY CORRUGATED HOSES

Flexible secure cover for secure operation

Annularly corrugated hose

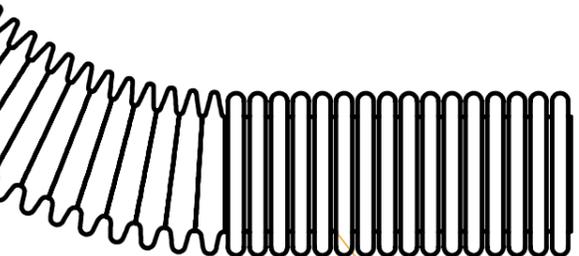


The distinctive feature

Almost at the same time as Flamanville two EPR reactors will be built in the Taishan Chinese nuclear reactor. Here, too, Witzemann supplied the appropriate protective sheathing for various electronic measurement cables. For handling reasons, the entire delivery took place in 33-metre tube sections with the corresponding couplings for assembly on site. A detailed assembly guide and various demonstrations ensured safe installation of the tubes on site.

Two almost structurally identical projects

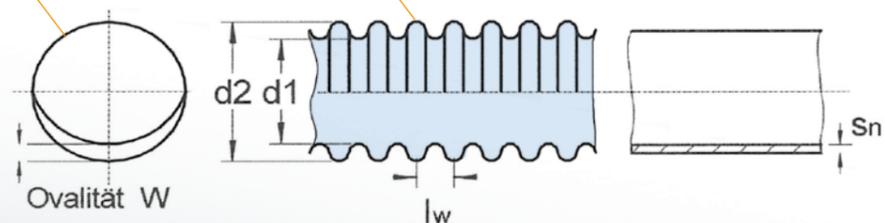
NPS	Flamanville 3	Taishan 1 + 2
Customer	AREVA	AREVA
Final customer / Operator	EDF	CNPEC / CNPDC
DN 10	3530 m	7308 m
DN 32	520 m	1145 m
Material	Magnifer metal	Magnifer metal
General Nuclear specifications	QN-100, -200, -300	QN-100, -200, -300



■ Slightly oval tube profile

■ Special, mechanically exceptionally strong corrugated profile

■ Metal tube for magnetic screening and to protect against mechanical damage such as buckling protection



APPLICATION 2: EXPANSION JOINTS

Compensating for heat expansion in the lines

Expansion joint



Cleaned with osmotic water, the expansion joint is now ready for dispatch.

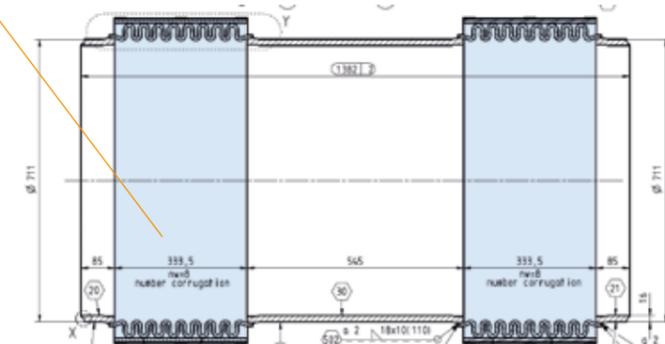
In case of accident, radioactive steam can penetrate into specific areas of the reactor. This is then extracted using special tubes. As this is very hot steam, the existing heat expansion of the pipes must be compensated for to ensure future safety. For this purpose three Hydra DN 700 universal expansion joints will be built into the pipes of the nuclear steam generator system. As flexible system elements for depression between two walls (3rd containment barrier).

The distinctive feature

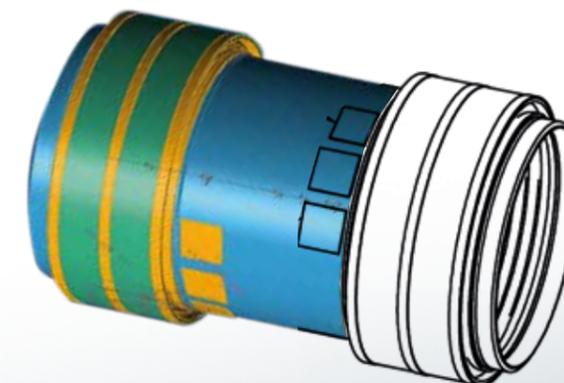
Essentially a standard expansion joint technically, here too the special feature lay in the requirements imposed by the nuclear industry on the production process. For example external production monitoring by up to 8 people for each production step as well as comprehensive certificates and tests. The test includes RT, PT, VT, LT, pressure testing, dimensional tests, welding monitoring, WPS, WPQR, welder certificates, Level III PT tester, customer manufacturer's plate, water analysis (chloride test), packaging acceptance (various indicators such as shock and moisture) & material in accordance with PMUC. All tests take place under an external monitor that must approve each individual step.

Technical design

■ External tube plates protect the bellows from mechanical damage



3D model



THE RIGHT PACKAGING – AN ESSENTIAL PART OF THE REGULATIONS

From halide-free film to shock indicators

In the Flamanville project, long-term packaging of 24 months was required.

The packaging

The delivery, like the production, is also subject to special customer regulations. So the pipe elements are additionally cleaned with osmotic water prior to dispatch in order to be able to deliver the components completely ferrite-free. The expansion joints also get moisture indicators before they are shrink-wrapped with a special halide-free film and drying agent and packed in boxes. Special regulations also apply to these. For example they must be fitted with shock indicators. If a transport box falls or is mechanically impacted or damaged, this will be recorded by the indicator. The box will then be sent back unopened and the usability of the expansion joint will again be tested. Only in this way can the extreme quality and lifespan requirements be guaranteed.



■ **Every box** is fitted with a shock indicator. This ensures that external effects during transport, such as a fall of the box, do not remain undetected.



■ **A moisture meter** continuously monitors air humidity inside the packaging



■ **Expansion joints** shrink-wrapped in halide-free film



REFERENCES

Other projects in the nuclear industry



Photo: IPP, Wolfgang Filser

Industry-References for products with nuclear application

Product	NPP
Expansion Joints	Flamanville 3, France
Magnifer metal hoses DN10 & DN32 for electromagnetic shielding	Flamanville 3, France
Magnifer metal hoses DN10 & DN32 for electromagnetic shielding	Taishan 1&2, China
Expansion Joints DN 40,50,80,100,300 & 500	MOX Fuel Fabrication Facility, USA
Expansion Joints	Forsmark, Sweden
Expansion Joints	Borssele, Netherlands
Metal hoses	Leibstadt, Switzerland
Expansion Joints	Grundremmingen, Germany
Valve spindle bellows	In more than 80 nuclear power plants worldwide

REFERENCES

CERN in Geneva

CERN is a major research institution in the canton of Geneva in Switzerland and is involved in fundamental physics research. In particular, research is done there into the structure of matter, using large particle accelerators. The most significant accelerator currently is the Large Hadron Collider, which entered operation in 2008.

CERN is derived from the French name of the council that was responsible for founding the organisation, the Conseil Européen pour la Recherche Nucléaire.

DESY in Hamburg

The construction of the first partial accelerator DESY (Deutsches Elektronen-Synchrotron), which gave the research centre its name, started in the year 1960. DESY's responsibility is to carry out fundamental scientific research.

In this, the research centre focuses on three things:

- Development, construction and design of particle accelerators;
- Study of the fundamental characteristics of matter and forces in the context of particle physics or high-energy physics;
- Research with photons, i.e. synchrotron radiation and free electron lasers in (among other fields) physics, chemistry, biology, geology and medicine.

D05 Fusion Stellarator Wendelstein 7-X in Greifswald

Behind the sonorous name of the Wendelstein 7-X is an experimental plant for research into nuclear fusion technology. The operator is the Max-Planck Society with its Institute for Plasma physics (IPP).

The main component of the experimental set-up there is a fusion plant of the so-called stellarator type (see table). The W7-X is used to do research into the physical and technical principles of nuclear fusion.

Technical data	Stellarator
Project	Wendelstein 7-X
Operator	Max-Planck Institute for Plasma Physics (IPP), Greifswald
Design	Stellarator (plasma is held in suspension only through the use of external magnetic fields, – no flow of energy in the pgroolasma)
Magnetic coils	from superconductors (deep-cooled to approx. 4 Kelvin (approx. 269 degrees celsius), up to 13,000 amps current strength)
Plasma	Volume: approx. 30 cubic metres Temperature: ca. 100 million C° Pressure: approx. 2 bar
Reactor	Mass: 750 t Diameter: 16 m

OUR PRODUCT RANGE

HYDRA Metal Hoses

Corrugated hoses from DN 6 to DN 300, for operating pressures up to 400 bar for temperatures from – 270 °C to max. 600 °C.

HYDRA Expansion Joints

Axial, lateral or angular expansion joints from DN 15 up to DN 12.000 with rotating flared flanges, fixed flanges, ends prepared for welding, ... in various materials like stainless steel, tantalum, Incoloy, ...

HYDRA Metal Bellows

Corrugated high pressure resistant bellows and membrane bellows for different applications.

HYDRA Hangers and Pipe Supports

Different types of maintenance-free hangers and supports for load bearing up to 500 kN.

HYDRA Bearings

floating, guide, and fixed bearings, roller bearings for insulated and non-insulated pipelines in the nominal diameter range from DN 15 to DN 600.

FLEXPORTE® – Sizing Software

Flexperte was developed especially for planners and designers for the selection of metal hoses, expansion joints, metal bellows and pipe supports with interface to PDMS, PDS.

