COCIR

SUSTAINABLE COMPETENCE IN ADVANCING HEALTHCARE

European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry

COCIR SRI

ANNUAL FORUM 2019

26 March 2019, 10.00 – 12.00

SRI SO FAR

- Ultrasound: 2005-2013
- MRI: 2009-20017

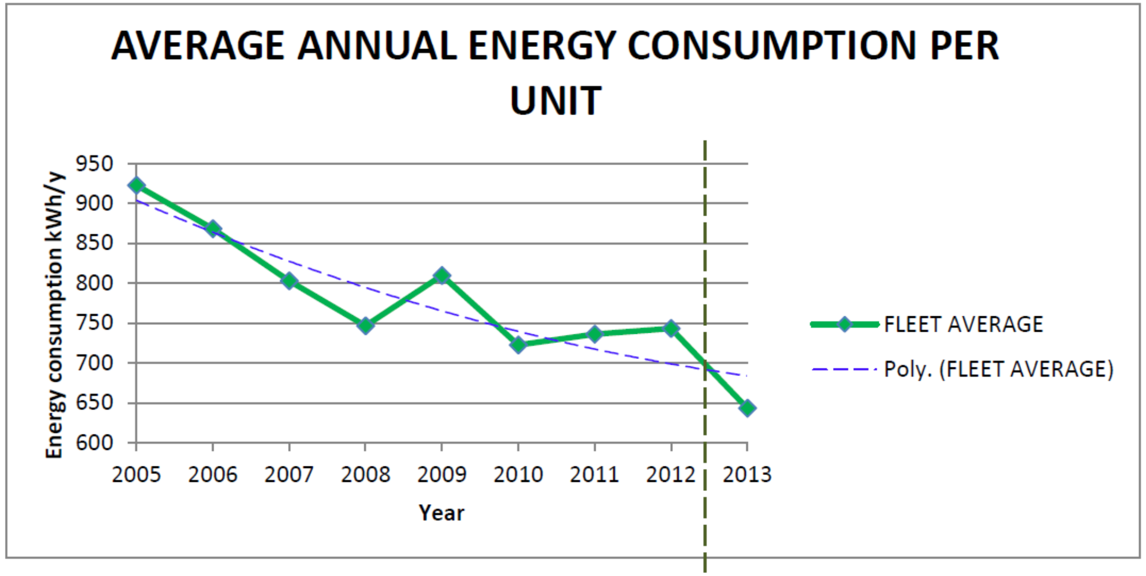
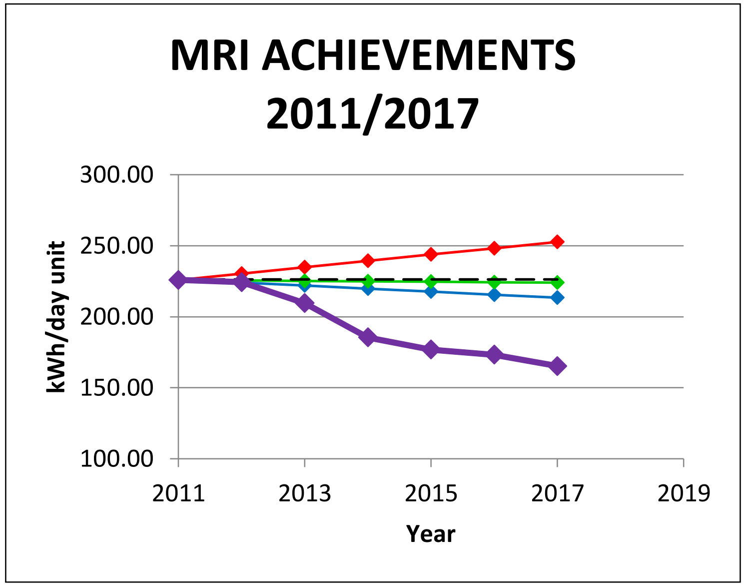
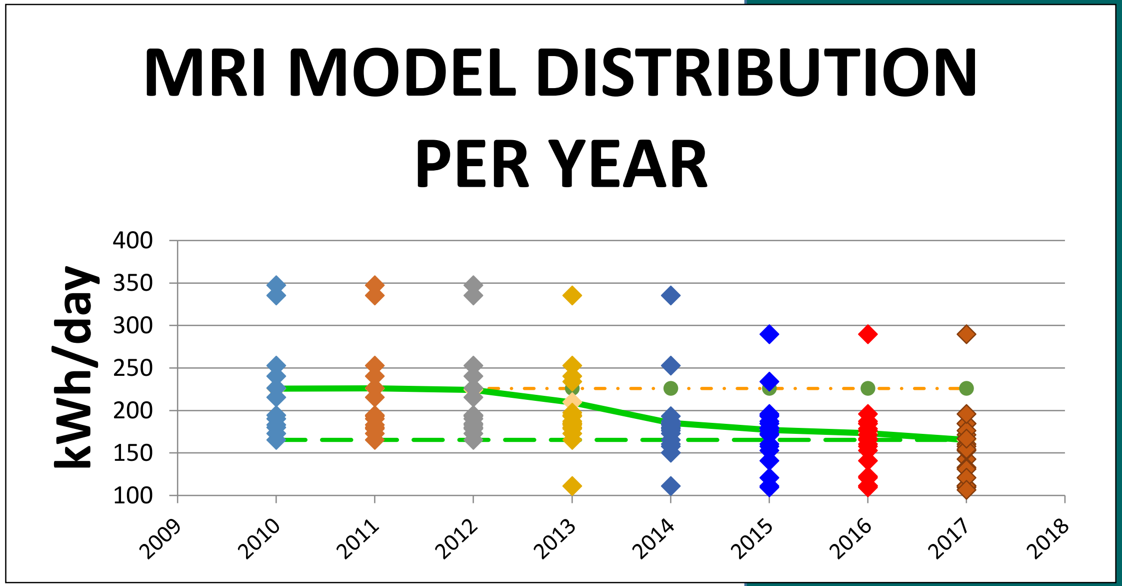


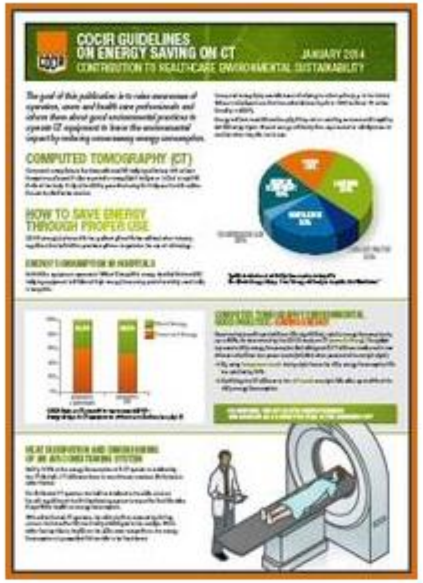
***Figure**: Ultrasound annual energy consumption per unit: market fleet average*



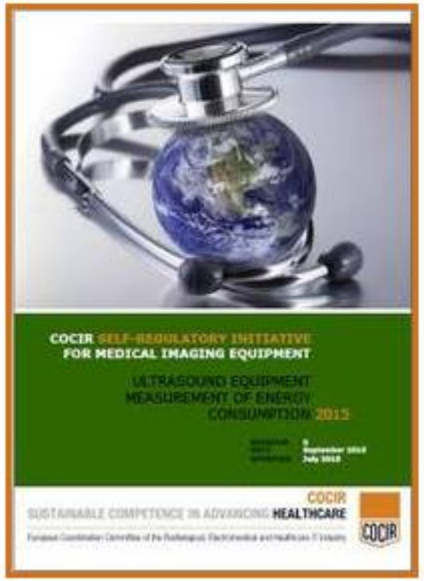


SRI SO FAR

COMPUTED TOMOGRAPHY



ULTRASOUND



MAGNETIC RESONANCE

RADIOGRAPHY

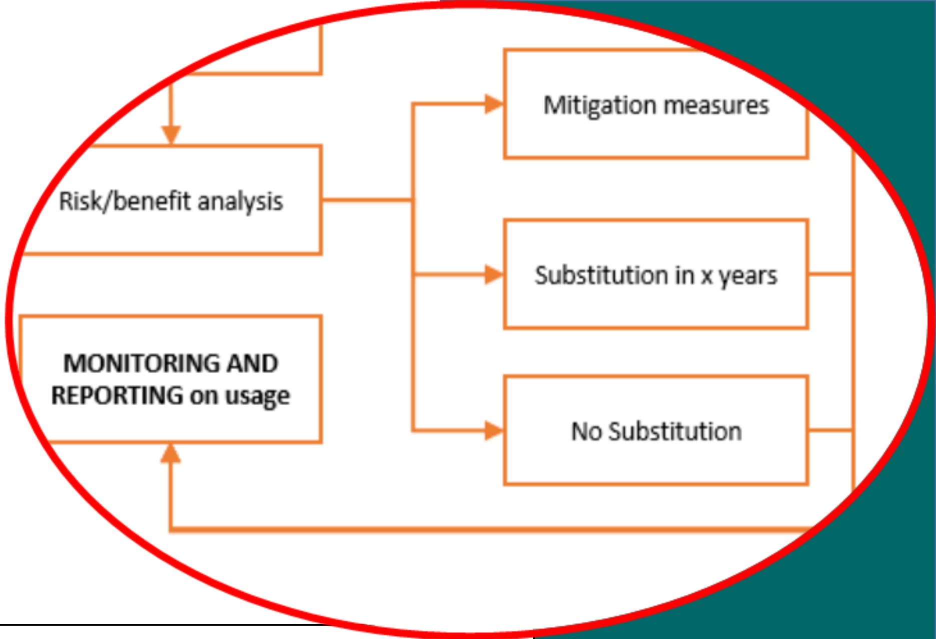
COCIR SRI

ANNUAL FORUM 2019

26 March 2019, 10.00 – 12.00

MANAGEMENT OF HAZARDOUS CHEMICALS

MANAGEMENT OF HAZARDOUS CHEMICALS



IDENTIFICATION OF CMRs
USED IN MEDICAL DEVICES

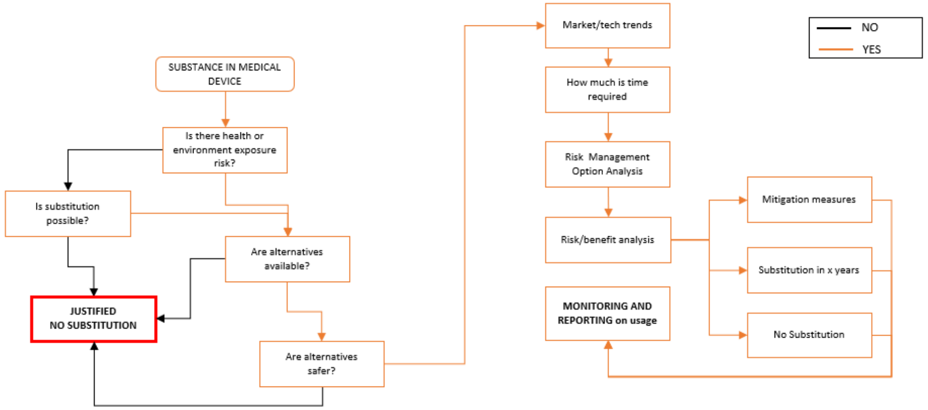
- ✓ Compose a list of substances that are **carcinogens, reproductive toxins and mutagens** of category 1A and 1B and **endocrine disruptors** with EU harmonised classifications that are in scope of Article 10.4.
- ✓ There are various lists published but the definitive one that should be used is the ECHA Classification and Labelling Inventory (C&L I)

Classification	Number listed
Carcinogen 1A	1,059 substances, of which 336 are harmonised classifications
Carcinogen 1B	1,707 substances, of which 692 are harmonised classifications
Mutagen 1A	232 substances, of which none are harmonised classifications
Mutagen 1B	900 substances, of which 429 are harmonised classifications
Reproductive Toxin 1A	692 substances, of which 27 are harmonised classifications
Reproductive Toxin 1B	1,572 substances, of which 232 are harmonised classifications

- ✓ Reduce the list from 1200 substances to 100, identifying only those used in **medical devices**

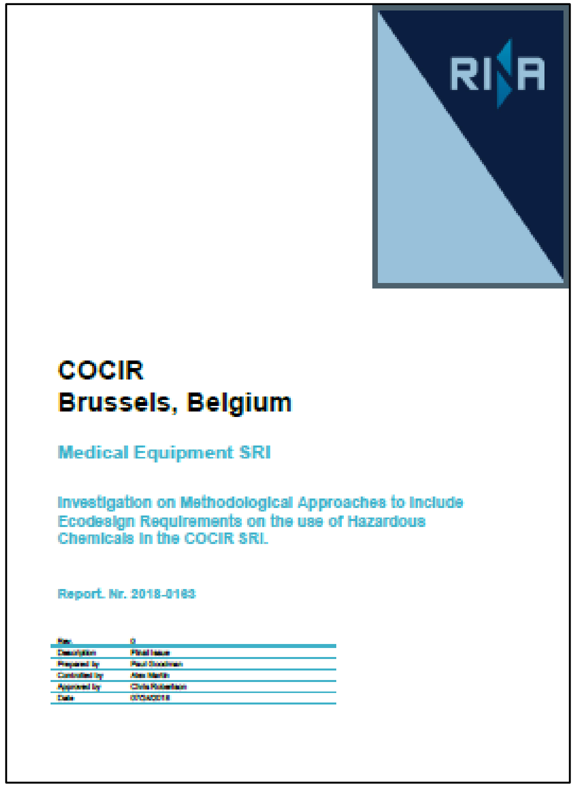
COCIR is going to contract RINA to perform the analysis
to come to a list of CMR
that may be used in medical devices

SUBSTANCE ASSESSMENT



COCIR STUDIES

- COCIR contracted RINA to perform an assessment on the methodological steps to assess a substance:
  - ✓ Exposure risk
  - ✓ Alternatives assessment
  - ✓ Global Trends
  - ✓ Time needed for substitution
  - ✓ Impact on innovation
  - ✓ Risk/benefit analysis



COCIR
Brussels, Belgium

Medical Equipment SRI

Investigation on Methodological Approaches to Include Ecodesign Requirements on the use of Hazardous Chemicals in the COCIR SRI.

Report. Nr. 2018-0183

Rev	0
Description	Final Issue
Prepared by	[illegible]
Controlled by	[illegible]
Approved by	[illegible]
Date	[illegible]

COCIR contracted RINA to perform an assessment on the CMR 1a, 1b and ED substances used in medical devices.

The list is being used by companies and has been included in BOMCheck to help sourcing info from the supply chain

	A	B	C	D	E	F	G	H
1		EC No.	CAS No.	Name all	Uses	Hazard classificati	Type	Applicable EU legislation
2	1			Benzidine based azo dyes: 4,4'-diarylazobiphenyl dyes, with the exception of those specified elsewhere in this Annex	Dyes of various colours, although some are banned by REACH in fabrics with skin contact	Carcinogen 1B	1	REACH Annex XVII
3	2	401-500-5	118658-99-4	(Methylenebis(4,1-phenylenazo(1-(3-(dimethylamino)propyl)-1,2-dihydro-6-hydroxy-4-methyl-2-oxopyridine-5,3-diyl)))-1,1'-dipyridinium dichloride dihydrochloride	Azo dye used in textiles, paper	Carcinogen 1B	1	
4	3			[Calcium-aluminium-silicate fibres with random orientation with the following representative composition (% given by weight): SiO2 50,0-56,0 %, Al2O3 13,0-16,0 %, B2O3 5,8-10,0 %, Na2O < 0,6 %, K2O < 0,4 %, CaO 15,0-24,0 %, MgO < 5,5 %, Fe2O3 < 0,5 %, F2 < 1,0 %. Process: typically produced by flame attenuation and rotary process. (Additional individual elements may be present at low levels; the process list does	Used as thermal insulation, also is a type of e-glass used mainly as fibre reinforcement of plastics	Carcinogen 1B	1	REACH SVHC
5	4	271-093-5	68515-50-4	1,2-benzenedicarboxylic acid, dihexyl ester, branched and linear	Plasticiser	Reproductive toxin 1B	1	REACH SVHC. Phthalate
6	5	284-032-2	84777-06-0	1,2-benzenedicarboxylic acid, dipentylester, branched and linear	Plasticiser	Reproductive toxin 1B	1	REACH SVHC. Phthalate
7	6	276-158-1	71888-89-6	1,2-benzenedicarboxylic acid: di-C₆₋₈-branched alkylesters, C₇-	Plasticiser	Reproductive toxin 1B	1	REACH SVHC. Phthalate
8	7	271-084-6	68515-42-4	1,2-benzenedicarboxylic acid: di-C₇₋₁₁-branched and linear alkylesters	Plasticiser	Reproductive toxin 1B	1	REACH SVHC. Phthalate
9	8	219-603-7	2475-45-8	1,4,5,8-tetraaminoanthraquinone: C.I. Disperse Blue 1	Blue dye used in plastics, fabrics, etc.	Carcinogen 1B	1	
10	9	202-918-9	101-14-4	2,2'-dichloro-4,4'-methylenedianiline: 4,4'-methylene bis(2-chloroaniline): salts of 2,2'-dichloro-4,4'-methylenedianiline: salts of 4,4'-methylenebis(2-chloroaniline)	"MOCA", used mainly to make polyurethanes (some used also for epoxy resins), but residues may exceed 0.1% acccording to ECHA	Carcinogen 1B	1	REACH SVHC
11	10		72319-19-8	2,7-naphthalenedisulfonic acid, nickel(II) salt	May be used as a green textile dye but uncertain and unlikely	Carcinogen 1A, Reproductive toxin 1B (Mutagen 2)	1	
12	11	420-580-2	151798-26-4	2-[2-hydroxy-3-(2-chlorophenyl)carbamoyl-1-naphthylazo]-7-[2-hydroxy-3-(3-methylphenyl)carbamoyl-1-naphthylazo]fluoren-9-one	Pigment (used in some photocopiers)	Reproductive toxin 1B	1	
13	12	239-622-4	15571-58-1	2-ethylhexyl 10-ethyl-4,4-dioctyl-7-oxo-8-oxa-3,5-dithia-4-stannatetradecanoate (DOTE)	PVC stabiliser. Mainly used in rigid PVC including transparent PVC, but may also occur in flexible PVC	Reproductive toxin 1B	1	REACH SVHC
14	13	400-600-6	71868-10-5	2-methyl-1-(4-methylthiophenyl)-2-morpholinopropan-1-one	Photoinitiator resulting in inclusion into a matrix, including application in coatings, adhesives and inks.	Reproductive toxin 1B	1	
15	14	209-321-2	569-61-9	4,4'-(4-iminocyclohexa-2,5-dienylidenemethylene)dianiline hydrochloride: C.I. Basic Red 9	Red dye	Carcinogen 1B	1	
[illegible]	[illegible]	[illegible]	[illegible]	4,4'-bis(dimethylamino)benzophenone:	Impurity in plastics and textiles from various dues and	Carcinogen 1B	[illegible]	[illegible]

PARALLEL ACTIVITIES

METHODOLOGY UNDER DEVELOPMENT

The EC gave mandate to SCHEER to develop the Guidance end 2017.

The SCHEER is requested to provide guidelines on the benefit-risk assessment of the presence of CMR phthalates.

The guidelines shall include guidance on how, for an individual device, to:

- Analyse and estimate potential patient or user exposure to the substance *(NOTE: not to environment)*
- Analyse possible alternative substances, materials, designs, or medical treatments
- To justify why possible substance and/or material substitutes, if available, or design changes, if feasible, are inappropriate in relation to maintaining the functionality, performance and the benefit-risk ratios of the product.

Once available this methodology will be analyzed by COCIR and adapted to the SRI scope and objectives

1st Public Hearing: 4 April 2019

www.oeko.de

Öko-Institut e.V.

Draft Manual Methodology for Identification and Assessment of Substances for Inclusion in the List of Restricted Substances (Annex II) under the RoHS 2 Directive

Prepared in the framework of the Study to support the review of the list of restricted substances and to assess a new exemption request under RoHS (RoHS Pack 15)

Freiburg, 22.10.2018

Reference: Specific contract No. 07.0201/2017/772070/ENV.B.3 Implementing Framework Contract No. ENV.A.2/FRA/2015/0008.

Draft

Fraunhofer

Released October 2010

COCIR

SUSTAINABLE COMPETENCE IN ADVANCING HEALTHCARE

COCIR CONTRIBUTION

On the Substance Review Methodology and the revision of the RoHS Substance Inventory

COCIR, the European Association of the Radiological, Radiotherapy and Healthcare IT Industry is happy to provide a contribution to the public consultation on the RoHS methodology.

COCIR companies support the objective of the RoHS Directive and have been committed to reduce the use of hazardous substances whenever possible and reasonable. Nonetheless experience shows that RoHS restrictions have a significant impact on companies, in particular the ones in the medical imaging device sector, where products have long design cycles (7-10 years), very long service life (10-15 years), are extremely complex (weighting up to 10 tons with more than 260.000 components and around 1.000.000 homogeneous materials).

COCIR therefore believes that the methodology that is used to assess substances for future restrictions has to be solid, objective and to be able to look at all the possible aspects to prove that a restriction is really justified, proportionate, effective and efficient.

COCIR provides some general comments regarding the proposed methodology here below, and more specific ones on the wording of the draft methodology in the annex.

General comments

1. **The RoHS Directive legally applies to the placing on the market of EEE (article 4.1)** by manufacturers and importers. This concept is clearly defined in the EU Blue Guide. "Placing on the market" does not include the manufacturing phase along the supply chain. For this reason, RoHS cannot legally restrict process substances that are not present in the final EEE. Restricting such substances can be done under REACH but not under RoHS.
2. **EU legislative measures have to be proportionate, effective and efficient.** The principle of proportionality is a basic principle of European legislation and EU measures have to be efficient and effective.
   - ✓ When the methodology assumes that substances that are not used or pose no risk may be restricted, it violates said principles. If there is no risk, there is also no benefit in restricting the use of the substance, therefore the measure cannot be proportionate: it imposes a burden with no corresponding benefit.
   - ✓ When the methodology assumes that a RoHS restriction could be adopted to solve problems created by illegal activities such as the use improper technologies or by illegal shipment to developing countries, it violates the principles of efficiency and effectiveness. For instance, the most efficient and effective way to deal with improper waste treatment activities is to make sure existing legislation is enforced and the best technologies are adopted.
3. **Is RoHS an effective measure to protect workers or the environment?** COCIR wonders if a risk in the work place or a risk for environment can be properly controlled by a RoHS restriction. Considering that a RoHS restriction would take 10 to 15 years (or more)

17 December 2018 *Page 1 of 20*

COCIR
SUSTAINABLE COMPETENCE IN ADVANCING **HEALTHCARE**

European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry

COCIR SRI

ANNUAL FORUM 2019

26 March 2019, 10.00 – 12.00

CRITICAL RAW MATERIALS

RECYCLING NIOBIUM

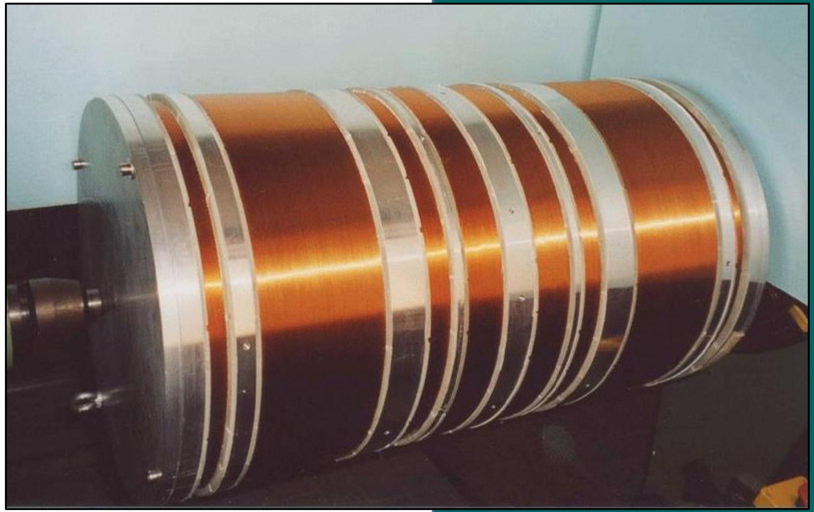
NIOBIUM IN MEDICAL DEVICES

- Niobium is mainly used in steel alloys and superalloys. 3% is estimated to be used in superconductors.
- Niobium-Titanium alloy is used in MRI magnets.
- The thin wires are embedded in a copper matrix for protection.
- The wiring is then encapsulated into resin.

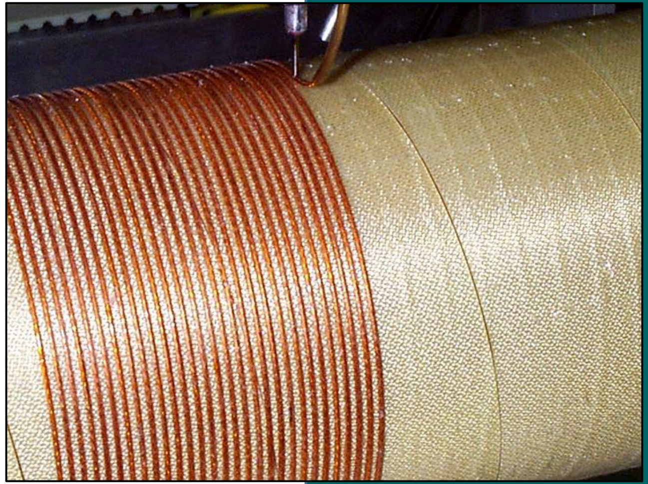
Fig. 7 A large size draw of Nb-Ti superconducting strand on a bull-block. Photograph courtesy of Oxford Instruments-Superconducting Technology.

SUPERCONDUCTIVE MAGNETS

- 4,5 tons of wire used per magnet
- Almost 19 km of wire per magnet.
- 17 kg of wire is wasted per unit on average, during the production process



Application	Weight	
Cu:NbTi	4500	Kg/unit
Cu	4100	Kg/unit
NbTi	457	Kg/unit
Nb	212	Kg/unit



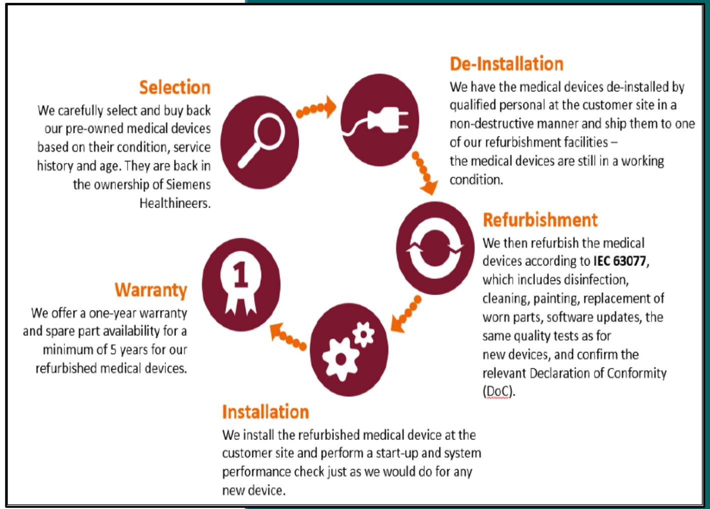
REFURBISHMENT AND REUSE

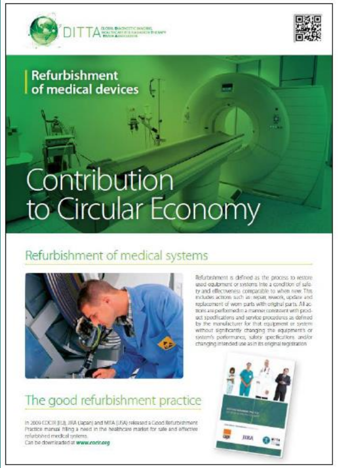
- Refurbishment extend the lifetime of MRIs restoring their functionality, safety and performance to a level comparable when they were new.
- By extending life of MRIs, 9,7 tons of virgin niobium are saved every year in EU and around 40 tons globally, to manufacture new magnets.

2016	UNITS SOLD	UNITS REFURB	RE/POMe %
MRI	871	46	5,3%
CT	993	52	5,2%
X-RAY	2942	152	5,1%
TOTAL			**5,2%**

Data from the COCIR SHARE market statistics tool

- Reuse of magnets in the production of new equipment is another activity in the frame of circular economy that prevents niobium to be lost.





In 2015 DITTA published a brochure highlighting the contribution of refurbishment to circular economy and to sustainability

REUSE OF RECOVERED NBTI

- The main uses of niobium is in high strength steel alloys and superalloys. Standards for these alloys have been reviewed and there are many alloys that contain both **niobium** and **titanium** which would remove the need to separate niobium from titanium.
- High strength alloys and superalloys are usually made by addition of primary ferroniobium (FeNb) to the melt under reducing conditions to prevent oxidation of niobium.
- Scrap alloys with a high niobium content are used to provide the niobium content but is usually “new scrap” which is a single alloy of known composition.
- There is no technical reason, though, why NbTi superconductor wire could not be used as a feedstock.

EN steel number	Short name	Nb content
1.4509	X2CrTiNb18[2]	(3 × C) + 0.30% up to 1.00% (C ⩽ 0.03%)
1.4511	X3CrNb17	12 × C up to 1.00% (C ⩽ 0.05%)
1.4526	X6CrMoNb17-1	7 × (C + N) + 0.10% up to 1.00% (C ⩽ 0.08%; N ⩽ 0.04%)
1.4542	X5CrNiCuNb16-4	5 × C up to 0.70% (C ⩽ 0.07%)
1.4550	X6CrNiNb18-10	10 × C up to 1.00% (C ⩽ 0.08%)
1.4565	X2CrNiMnMoNbN25-18-5-4	Up to 0.15%
1.4580	X6CrNiMoNb17-12-2	10 × C up to 1.00% (C ⩽ 0.08%)
1.4590	X2CrNbZr17	0.35%–0.55%
1.4595	X1CrNb15	0.20%–0.60%
1.4607	X2CrNbTi20	Up to 1.00%
1.4621	X2CrNbCu21	0.20%–1.00%
1.4634	X2CrAlSiNb18	(3 × C) + 0.30% up to 1.00% (C ⩽ 0.03%)
2.4600	NiMo29Cr Nicrofer® 6629, Hastelloy® B-3	Up to 0.40%
2.4619	NiCr22Mo7Cu Inconel® G-3, Nicrofer® 4823hMo	Up to 0.50%
2.4660	Nicrofer® 3620, Incoloy® alloy 20	NiCr20CuMo 8 × C up to 1.00% (C ⩽ 0.07%)
2.4856	NiCr22Mo9Nb Inconel® 625, Nicrofer® 6020	3.15%–4.15%
2.4868	NiCr19Fe19Nb5Mo3 Inconel® 718, Nicrofer® 5219	4.7%–5.5%
Superalloy	Inconel 713C	contains 0.8Ti and 2Nb
Superalloys	Inconel 738LC, Inconel 939, Mar 200, Rene 220, Rene N4, all contain Ti and Nb[3].	
Nickel based superalloy	CMSX-10	Contains 0.2Ti and 0.1Nb

MRI MAGNET RECYCLING

There are 3 ways to cut a magnet coil and remove the resin:

- ✓ Torcing: using a propane torch to burn off the resin. It is effective at removing the resin, but it produces a lot of smoke and dust and causes metal loss and diminished quality.
- ✓ Mechanical separation: the coils is cut to small pieces with mechanical cutters. The wire is mechanically separated from the resin.
- ✓ Pyrolisis: in a temperature, pressure, oxidation controlled, inert-gas atmosphere, the furnace runs at about 450 degrees Celsius, resin-free copper and niobium-titanium wire is produced. Low generation of pollution.

MRI MAGNET RECYCLING TODAY:
SMELTING

- Recovered wire is sent to smelting to recover copper.
- Niobiumis stable in air but oxidises when heated at >200°C to form Nb_2O_5.
- When MRI scrap is recycled, this is usually carried out in a basic oxygen furnace or electric arc furnace. Usually, niobium-containing alloys are not segregated and so the mixed scrap metal is melted to make lower grade steels and the niobium content is diluted or oxidised and lost.

- **Recovering niobium:** slug containing niobium can be heated in a mixture of carbon monoxide and chlorine gases. Carbon monoxide is a reducing agent and the ratio of gases affects the product. With excess carbon monoxide, carbides can be produced, but with lower concentrations, volatile chlorides are produced, including the chlorides of niobium, tantalum and titanium.

MRI MAGNET RECYCLING TODAY

REFINING*

- Scrap containing niobium is pulverised to small particles which are then leached in a column with a solution of alkali sodium cyanide for 15 days. This extracted 48.1% of the niobium content. The concentration of niobium in the leach solution is very low, but can be absorbed by active carbon with a recovery rate of 98.2%.
- Most electronics scrap contains very little niobium so its recovery is uneconomic. However, scrap from MRI including the superconductor cables may have sufficient niobium to make this process economically viable for niobium recovery.

*Recovery of Gold, Silver, Copper and Niobium from Printed Circuit Boards Using Leaching Column Technique, Ricardo Montero, Alicia Guevara and Ernesto de la Torre, Journal of Earth Science and Engineering 2 (2012) 590-595.

MRI MAGNET RECYCLING TODAY
HIDROMETALLURGY

- Kuusakoski, Finland has recently (2018) developed a process for recycling superconductor scrap that contains NbTi or Nb_3Sn_5. The process involves using electrochemical dissolution to dissolve copper, but leaves NbTi wires which can then potentially be used as a superalloy feedstock.
- Kuusakoski has developed a pilot scale process in Finland.
  - Copper is selectively dissolved by electrochemical dissolution in sulphuric acid. This yields a solution of copper sulphate with sulphuric acid from which copper metal can be electrowon leaving sulphuric acid for reuse.
  - It may be possible to carry out electro-dissolution and electrowinning simultaneously so that as copper dissolves at the anode, metal is simultaneously electrodeposited onto the cathode.

REUSE OF NBTI OR NB AND TI

It is possible to reuse recovered NbTi alloy to make superalloys or possibly to make new superconductors, however, if neither of these are viable, then separation of the two metals is possible:

- Titanium and niobium are attacked and dissolved by leaching in strong hot acid.
- Niobium has to be dissolved hydrochloric acid otherwise it forms a variety of polymeric complexes in solution if sulphuric or chloridric acids are used
- Various separation methods are possible from fluoride solutions:
    - Fractional crystallisation
    - Solvent extraction

ECONOMICS

- The market price of niobium metal between 2010 and 2018 has been $40,000 to $42,000 per ton.
- Copper metal would also be recovered by a recycling process which currently has a metal price of $5,900per ton.
- According to COCIR estimation:
  - ✓ 212.7kg of niobium is present in MRI unit for a total value of €8,500 to €9000..
  - ✓ 4.2 tons of copper is present in MRI unit and so the value of copper would be around €22,000 per unit.
  - ✓ The total value of niobium and copper from a MRI unit is therefore 31,000€ per MRI.
- It is very difficult to estimate the number of MRI sent to recycling in EU each year as:
  - ✓ Hospitals do not necessarily contact the manufacturer (WEEE Directive) and sell the MRI directly to recyclers.
  - ✓ The recycled MRI units are reported under the more general “Category 8” under the WEEE reporting system
  - ✓ Since 2018 waste Medical Imaging Devices are reported in a even more general category “Large appliances”

ECONOMICS

- There are currently 8615 installed MRIs in EU (2016 data), for a total **1800 tons of niobium**.
- In 2017, new 918 MRIs were placed on the EU market, using around **190 tons of niobium**.
- Estimating 50 MRIs scrapped every year (tbc) in EU and 192 worldwide

	EU (Tons/y – 50 MRI/year)	Value of metals from EU EOL MRI EU (€)	Global(Tons/y) – ca. 192 MRI/year	Value of metals Global (€/y)
Niobium	10,6	447,000	40,7	1,709,000
Copper	210	1,090,000	808	4,194,000
TOTAL		1,537,000		5,903,.000

CONCLUSIONS

- Kuusakoski stated that their process has a capacity for 200 tons of copper per year / 20 tons of NbTi which would correspond to around 40/50 MRIs per year.
- The capacity of Kuusakoski is therefore sufficient to treat MRIs disposed of in EU (Kuusakoski also stated they can scale up the capacity if required).
- The de-installation and transport of full MRI systems for recycling could be antieconomic. For MRI only (no deinstallation) the return is positive.
- Treating magnet coils only is considered by Kuusakoski to have a significant positive net value.

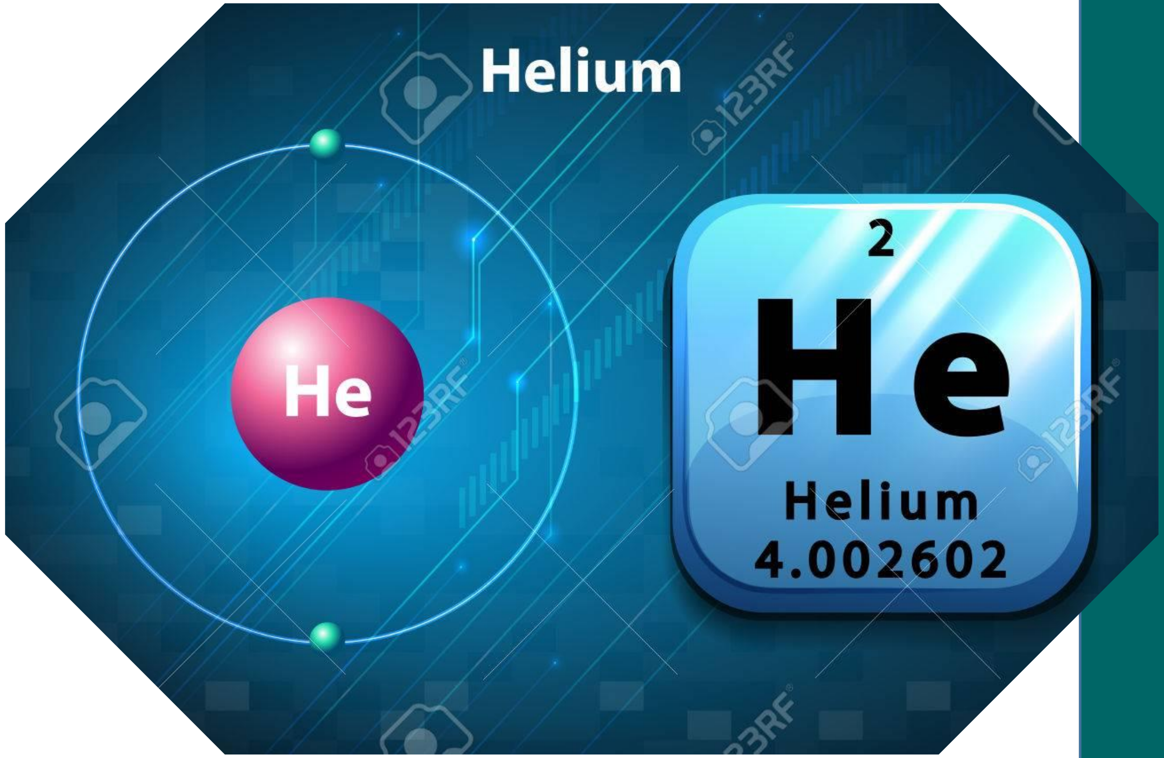
CONCLUSIONS

- It is technical feasible to recover niobium from MRI magnets
- There is already enough capacity to treat all MRIs (tbc) disposed of every year
- Around 21,5 tons of NbTi can be recovered every year (10 tons of niobium)

COCIR SRI

ANNUAL FORUM 2019

26 March 2019, 10.00 – 12.00



CRITICAL RAW MATERIALS

HELIUM

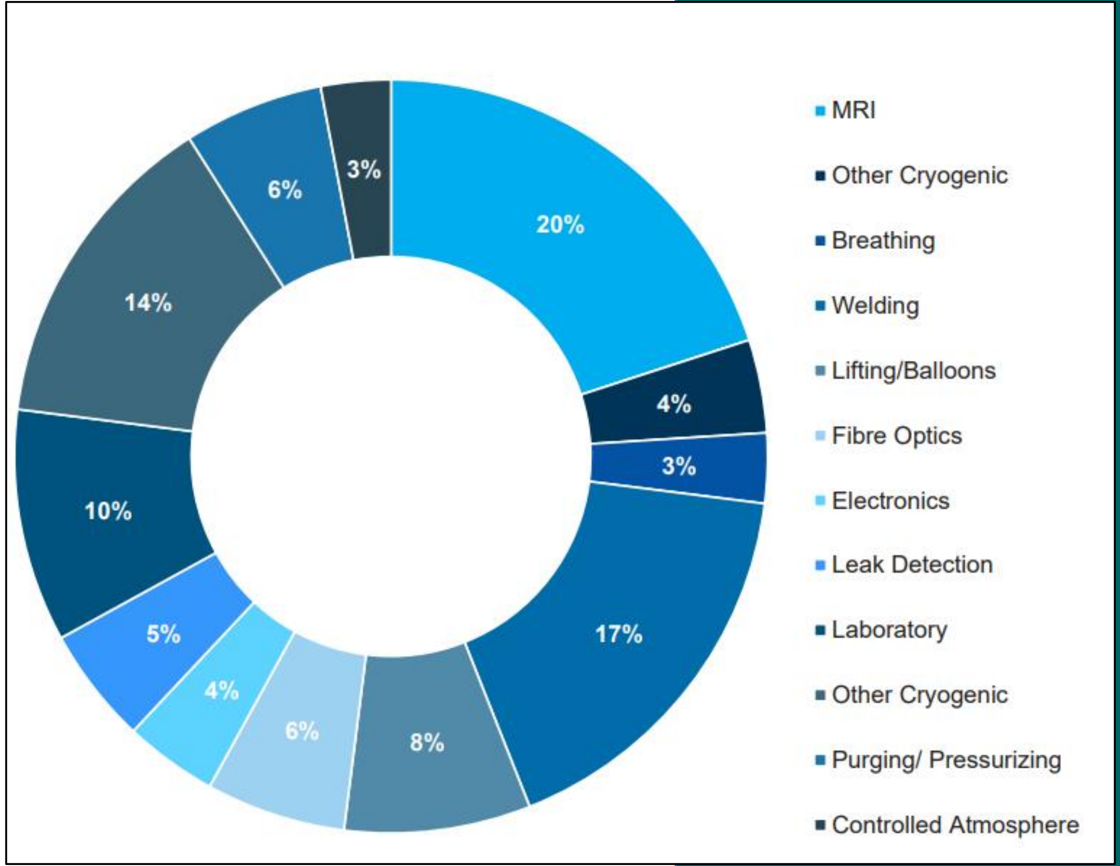
HELIUM

- Helium is a critical raw material for Europe
- On Earth it is relatively rare—5.2 ppm by volume in the atmosphere.
- Most terrestrial helium present today is created by the natural radioactive alpha decay. This radiogenic helium is trapped with natural gas in concentrations as great as 7% by volume, from which it is extracted commercially by fractional distillation.
- Prices in the 2000s had been lowered by the decision of the U.S. Congress to sell off the country's large helium stockpile by 2015.
- Global demand for helium has risen by 10% per year over the past decade to an estimated 8 billion cubic feet. This far exceeds current supply which sits at only 5.4 billion cubic feet. This shortfall has placed an enormous strain on the price of helium, driving it up to an all-time high this year to $119 per thousand cubic feet. This represents an 11% increase over 2017. This trend is likely to continue into 2020, where the value of the helium market could exceed $1.5 billion.

HELIUM USED IN MRI

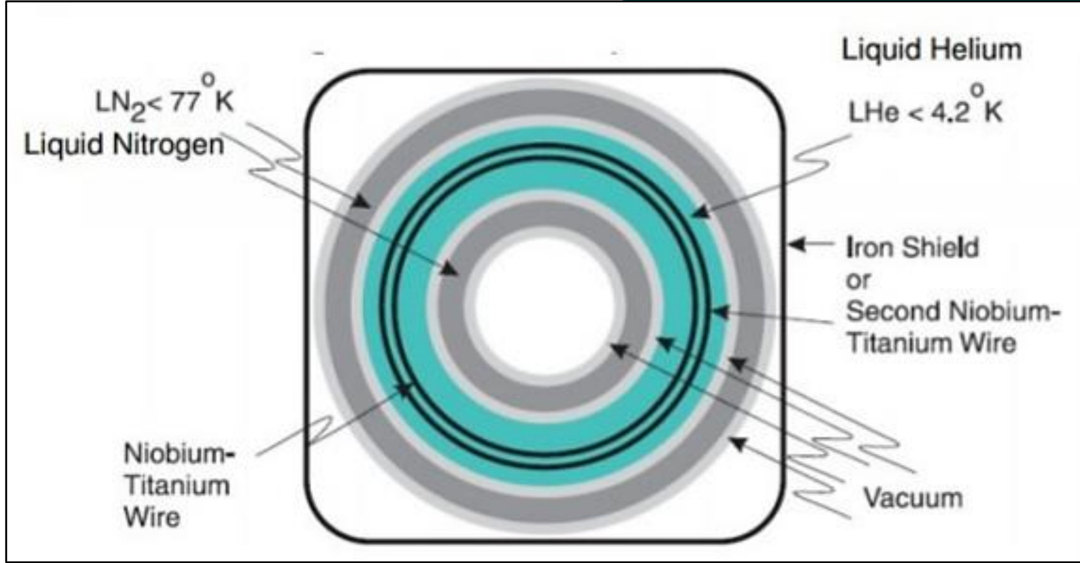
A quarter of the world's helium is used for cryogenics in MRI machines.

- Around 2000 liters per MRI are used on average to cool down the magnet to 4 Kelvin through a Gifford-McMahon cryocooler.
- There are around **8500** MRIs installed in EU which corresponds to **17000**m3 of helium.
- **25000** MRIs estimated worldwide.
- **912** new MRI where placed on the market in 2017 (1824 m3).



HELIUM BOIL-OFF AND ZERO BOIL-OFF TECHNOLOGY

- In the past MRI needed to be regularly refilled as the helium was boiling off. They relied on two refrigerator-cooled shields in the vacuum space to reduce the heat load to less than 50 mW, resulting in a loss of less than 1 liter of helium per day. The boil-off rate was from 0,02% per day to 0,14% per day depending on the models
- In the 90s, zero boil-off magnets where introduced. A cryocooler re-condenses the helium. Nonetheless:
  - Some helium is lost during the assembly of the magnet due to accidental quenches (most of the helium can be recovered thanks to “recovery systems”)
  - Some helium is lost during transportation to the final site.
  - Quenching the magnet for emergency reasons means loosing all the helium at once (65% of MRI users experienced a quench every 10 years – *source Philips*).
  - Restaring a magnet after a quench and bringing it back to 4k involves additional losses.
- It takes 8kW of energy to generate a 1W of cryo-cooling

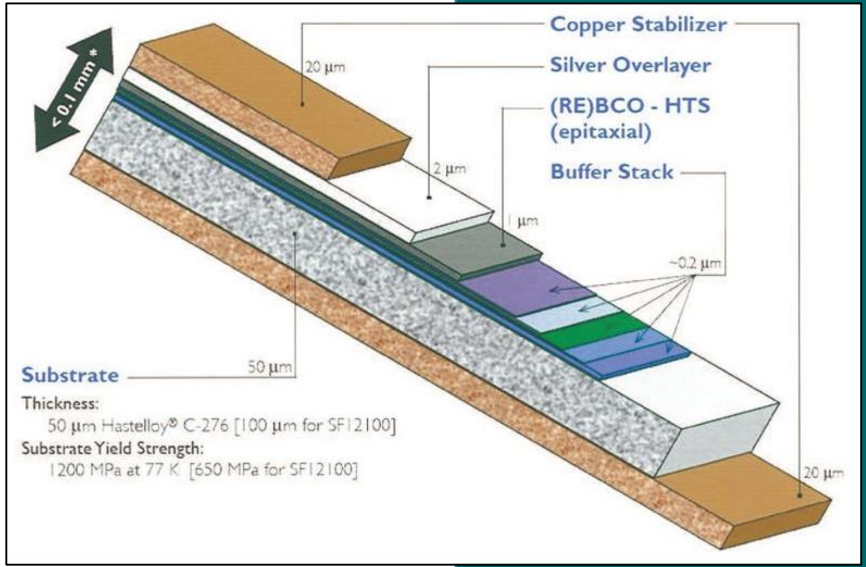


SAVING HELIUM

- There is 1 simple way to avoid losing helium in MRI: not using helium
- This can be achieved in 2 ways:
  - High-temperature superconductive materials
  - High efficient cryocoolers

HIGH TEMPERATURE SUPER CONDUCTORS

- There are high-temperature superconducting materials such as Yttrium Barium Copper Oxide (YBCO) tape.
- This material remains superconducting at temperatures above 77K, although for a practical magnet an operating temperature of about 40K to 50K would be ideal.
- Being able to run the magnet at 40K to 50K instead of 4K would allow a simpler and therefore more reliable refrigerator to be used, and the electrical energy required to keep the magnet cool could probably be reduced to around **1kW**.
- YBCO tape is currently 200 to 300 times more expensive than Niobium Titanium wire, which means that its use in MRI scanners does not at the moment make economic sense.



EFFICIENT CRYOCOOLERS

- Helium is used to absorb the heat produced by the MRI. Helium evaporates maintaining the temperature below 9 Kelvin and is recondensed with the cryocooler.
- Helium is used in large quantity to provide a buff.
- New more efficient pulse tube and 2-stage Gifford-McMahon cryocoolers are able to maintain temperatures below 9K without the need for helium, or with just a small amount of helium
- A few hundred liters of liquid helium or less would actually be sufficient to keep the magnet superconducting, so the main challenge in developing magnets without a large helium buffer volume is to make the refrigeration system so reliable that it never fails, or so efficient that it can re-cool the magnet without using much external helium after a failure.
- Such technology would also allow quenching for emergency reasons, with very reduced losses, if none at all.