SELF-REGULATORY INITIATIVE FOR MEDICAL IMAGING EQUIPMENT

MAGNETIC RESONANCE

MEASUREMENT OF ENERGY CONSUMPTION

DRAFT REPORT FOR DISCUSSION WITH THE ECODESIGN CONSULTATION FORUM

MARCH 2012

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1. INTRODUCTION

The Energy-related Products (Ecodesign) Directive, 2009/125/CE, enables the European Commission (EC) to set Ecodesign requirements through new regulations for any group of products which uses energy. In 2007, Medical Devices were identified as a "Priority A" product group by the European Commission for future regulation.

COCIR Companies presented in 2009 a Self-regulatory Initiative for Medical Imaging Equipment, committing to improve the environmental performances of their products.

The Steering Committee decided to develop ecodesign targets for magnetic resonance and established a working group from the manufacturers of MRI systems.

The outcome of the group was an agreed upon procedure for measuring typical energy consumption of MRI equipment. This procedure defines specific states of system operation and instructions for determining a set of scanning protocols to be analysed. For each product in scope, the sum of sequence durations and the power draw of non-scanning states are recorded.

2. SCOPE

This methodology can be used to measure all superconducting cylindrical-magnet whole-body MRI systems.
The use of the present methodology to measure permanent magnet open MRI would need to be investigated.
The methodology is not suited for the measurement of technologies combining MRI with other Imaging systems, such as MRI/CT or MRI/PET.

3. DEFINITIONS

Energy: The capacity to do work. In this document, the unit of energy is kilowatt-hours (kW·h).

Off mode: The system functions into the minimum energy consumption state that the typical user can access, through selection of off or shutdown, at the operator console. The power draw of the system is to be measured in this state.

Power: The rate at which energy is generated or consumed. In this document, the unit of power is kilowatts (kW).

Procedure Type: An exam is a collection of scans for an individual patient. "Procedure Type" refers an exam for a specific anatomy or type of exam. (e.g. Abdomen or Vascular).

Ready-to-scan mode: This mode represents the state of the system during patient handling and/or archiving, between individual scans. The power draw of the system is to be measured in this state.

Scan mode: The MRI is actively scanning the patient to generate the image by sending high frequency waves and reading the resulting variations in the magnetic field. The computing system interprets the data and generates the image.

Sequence Duration: Sequence duration is the time the system is actively scanning, during an exam. As the duration is determined by the details of the MRI scan prescription and product capabilities, each sequence's duration has to be determined on a per-product basis.

Service/Diagnostic: During the course of a typical day, a system may go into a lower power state where it is available for service access, such as remote diagnostics, but not necessarily in a ready-to-scan state. The power draw of the system is to be measured in this state.

4. SYSTEM POWER MODES

The operation modes are defined as "Off", "Service/Diagnostic Access", "Standby", and "Scanning". The energy consumption differs between the modes and that the transition between modes occurs by either operator selection and/or by timeout.

The anticipated power of these modes, from high to low, is:

Scanning **>** ***Ready-to-scan*** **>** ***Service/Diagnostic*** **>** ***Off***

The table below shows a possible state transition order, for an MRI system.

Initial State	Transition To	Method
Off	Service/Diagnostic	Operator starts system
Service/Diagnostic	Ready-to-scan	Operator prepares a scan
Ready-to-scan	Scanning	Operator starts a scan
Scanning	Ready-to-scan	Scanning completes
Ready-to-scan	Service/Diagnostic	Operator selection or timeout
Service/Diagnostic	Off	Operator turns off system

5. DAILY OPERATION

Typical daily system operation is set as follows:

Mode	Duration
Off	12 hours
Service/Diagnostic	2 hours
Scanning and Ready-to-scan	10 hours

The typical daily energy consumption of a MRI system is the sum of the energy consumption for each of the three time periods.

5.1. OFF

During the 12 hours of off time, the system is assumed to be in a low power mode. The power measurement for "off" is recorded 30 minutes after the operator selects this mode, to ensure that all elements of the system have established low power operation.

5.2. SERVICE/DIAGNOSTIC ACCESS

Two hours are allocated for service and/or remote diagnostics. The system is not required to be in a ready-to-scan state. If no low power mode is available, the system is supposed to be in ready-to-scan mode.

5.3. SCANNING AND READY-TO-SCAN

During the 10 hours of operation, the system is assumed to transition between two modes: Ready-to-scan and scan.

To describe operation, two sources were used. First, the IMV Medical Information Division 2007 MRI Market Summary Report, published May 2008, was used to determine the distribution of procedure types.

The 2007 MRI IMV Market Summary Report procedure distribution is:

Head	24%
Spine	25%
Abdomen	24%
Extremity	19%
Angio	9%

Second, within each procedure type, the specific sequences comprising the exam were selected based on the German "Guidelines of the Federal Medical Council for Quality Assurance of magnetic resonance imaging" (BAK) and the "guidelines on criteria for quality assessment in nuclear magnetic resonance imaging pursuant to § 136 SGB V i.V.m. § 92 SGB V, Section 1 of the Federal Committee of Physicians and Sickness Funds (Quality assessment guidelines for magnetic resonance imaging).

27 most typical sequences have been defined and listed in the template that can be downloaded with this document from the COCIR website.

The duration of each examination is unique per product and is the sum of:

- the total of "Sequence Duration" times
- the time for "Patient Handling and Administration Time",

Each manufacturer is responsible for determining the duration of each sequence (see chapter 11.4).

The patient handling and administration time can be measured performing examinations on a patient or phantom taking care of simulating all patient handling operations. In alternative average values measured by COCIR in during real examinations could be used:

Examination	Average ready-to-scan time
Head:	00:14:21
Spine:	00:13:41
Abdomen:	00:22:43
Knee:	00:14:10
Angio:	00:16:07

The measured durations are combined with the procedure distribution percentages to determine the number of examinations per day and then the energy consumption for the 10 hour period of operation can be derived. These measurements are captured the template "MRI – template for data collection" (available for download at www.cocir.org).

6. RESOURCES

6.1. PERSONNEL

An engineer or technician familiar with the power distribution of the system and power electronics safety.
An engineer or applications specialist familiar with scanner operation and the prescribing of clinical protocols**.**

7. UNIT UNDER TEST (UUT)

System Configuration: System configuration should be recorded and configured to perform the set of specified procedures with an appropriate surface coil.

Installation: The system shall be installed and calibrated according to its specification, including all system-critical items needed to perform a basic scan, e.g. gradient amplifiers, RF unit, MR coils needed for the specific measurements, reconstruction engine(s), required electronics such power supplies, controllers, console/computer, cryogen compressor, water heat exchanger (facility cooled water is provided), patient table, magnet and helium-conservation equipment.
Any equipment and accessories beyond basic product offering and not required for a basic scan, or customer-provided equipment, e.g. optional MR coils, patient vital signs accessories, facility-provided cooling water equipment and hardware for advanced medical applications shall not be included in the measurement.

Environmental Conditions: The measurements are to be taken at a steady-state operating temperature, and within manufacturer's specified ambient temperature and humidity limits.

Measurement: Prior to each mode's measurement, the equipment shall remain in that mode for sufficient time to allow temperature and other pertinent transient conditions to stabilize.

Emulated System: For sequence duration determination, it is permissible to use a device that emulates the hardware capabilities of the system, and uses the product software, to ensure the same prescription restrictions as a full system.

7.1. POWER MEASUREMENT DEVICE

A device capable of measuring 3-phase voltage and current and calculating the integral of power with respect to time (energy) or a calibrated power meter able to sample average power ratings.

Examples of power measurement equipment:

Hioki 3197 or 3198	Power Quality Analyzer
Hioki 9660	CAT III Clamp on Sensor (100A)

8. COCIR MRI DATA COLLECTION SPREAD SHEET

The data obtained according to the present methodology have to be filled in the appropriate template that can be downloaded from the COCIR website www.cocir.org.

9. DELIVERABLES

The deliverables for this procedure are:

- Power measured in Off mode
- Power measured in Ready-to-scan mode
- Power measured in Service/Diagnostic Access mode
- Power measured in Scan mode (average value) for each sequence
- Duration of each sequence
- Energy consumption per examination

10. INSTALLATION OF POWER MEASUREMENT DEVICE

The power measurement device shall be installed onto the input to the main disconnect panel of the system to ensure that all energy consumption of the MRI equipment is captured, including the cryo-cooler.

11. MEASUREMENT OF POWER AND ENERGY

11.1. OFF MODE POWER MEASUREMENT

1) Ensure that the power meter is on and functioning.
2) Select "off" or "shutdown", the minimum energy consumption state that the typical user can access, from the operator console.
3) Wait for 30 minutes to ensure that all system elements have established low power operation.
4) Measure the average power draw (rate of energy consumption), for a period of 10 minutes. If the system has a variable power usage in off mode, the measurement duration shall be amended to one complete power usage cycle, which shall be taken to be the cycle from minimum to maximum usage.
5) Record this value, in kilowatts.

11.2. SERVICE/DIAGNOSTIC MODE POWER MEASUREMENT

1) Ensure that the power meter is on and functioning.
2) Turn on the system, from the operator console.
3) Wait for 15 minutes to ensure that all applicable system elements have been powered on.
4) Measure the average power draw (rate of energy consumption), over a 10 minute interval.
5) Record this value, in kilowatts.

In case the MRI is not able to switch to a lower energy mode for service/diagnostic, the ready-to-scan power rate has to be used.

11.3. READY-TO-SCAN MODE POWER MEASUREMENT

1) Ensure that the power meter is on and functioning.
2) Prescribe a patient and execute any scan to ensure that the system is functioning.
3) After the scan completes, record the average power draw (rate of energy consumption), over a 10 minute interval. Ensure system remains in the same state throughout the measurement.
4) Record this value, in kilowatts.

11.4. SCAN MODE ENERGY MEASUREMENT

Setting up Scan Programs
Prepare a scan program for each exam type according to the user manual using the parameters defined in Appendix I. If it is not possible for the MRI system under test to use a certain sequence specified in the Appendix I, use a sequence as close as possible to the sequence specified given the same contrast and diagnostic results.
Store the scan programs for later usage on the same MRI system or MRI system type.

Measurement during scan with equipment actively scanning

Procedure for Power Determination using exam type average:
1) Set the equipment to Ready-to-Scan mode (according to 11.3).
2) For each exam type "et":
3) Take time "t_s" and energy value "E_s" and start scan program
4) After completion of scan program: take time "t_e" and energy ready "E_e"
5) Calculate average power Pet = (E_e - E_s) / (t_e - t_s).
6) Consistency check: t_e - t_s shall not deviate more than a few seconds from the sum of sequences' duration "d_s".

Procedure for Power Determination using power sampling:
1) Set the equipment to Ready-to-Scan mode (according to 11.3).
2) For each exam type "e_t":
3) Start scan program and record power sampling.
4) After completion of scan program: evaluate average power Ps for each sequence as outlined in section 3.

11.5. SEQUENCE DURATION DETERMINATION

The exact prescription of each sequence is to be determined by the individual member manufacturers. Three criteria should be considered, when determining the prescription parameters:

1) Parameters defined in Appendix I must be met.
2) SAR and dB/dt limits should not exceed IEC60601-2-33 First Control Mode restrictions.
3) The listed contrast type must be preserved (i.e. PD, T1, or T2-weighted)
4) Clinical considerations (i.e. reducing breath hold time for abdominal scans, or a minor adjustment in default TR to obtain the minimum required number of slices within one acquisition).

Record the duration of each sequence, as calculated by the system's software and displayed in the system's user interface.

12. HOW TO USE TEMPLATES

The methodology is complemented by an excel spread sheet where the measured data have to be filled in. The spread excel sheet is already equipped with formulas that provides the results.

The following data need to be filled in the template:

Measured data	Estimated data common to all Companies
1. Power consumption in off mode 2. Power consumption in ready-to-scan mode 3. Energy consumption for each sequence 4. Duration of each sequence	Stand-by-time for each examination (times in-between-scans) reported in **table XX**

Template for Head examination
Orange cells: to be filled with measured data
Grey cells: data derived by formulas.

Start time	Action	Endtime	Sequence duration	Power / kW	Time / h	Energy / kWh/sequence
9:00:00	Recorded start time					
	patient preparation and positioning; patient data entry					
	localizer		00:00:10	60,00	0,0028	0,17
	slice planning / adjustments					
	t2_tirm_tra_dark-fluid_320		00:04:32	60,00	0,0756	4,53
	slice planning					
	t2_tse_sag_512		00:03:45	60,00	0,0625	3,75
	ep2d_diff_3scan_trace_p2		00:01:39	60,00	0,0275	1,65
	slice planning					
	t1_se_tra_320		00:02:53	60,00	0,0481	2,88
	contrast agent injection					
	t1_se_tra_320		00:02:53	60,00	0,0481	2,88
	slice planning					
	t1_se_cor_320		00:02:25	60,00	0,0403	2,42
	patient out and data archiving					
	Recorded end time	9:33:00				

Start	Action	End	Total time			
9:00:00	average head examination total	9:33:00	0:33:00	kW	Time	kWh
	sum scan time		0:18:17	60	0,30	18,28
	sum stand-by		0:14:43	15,00	0,25	3,68
	control calculation		0:33:00		**Total**	**21,96**

The calculation sheet requires the following information to be filled in:

- Power consumption in off and ready-to-scan mode
- MRI product name
- Product Category

Summary to calculate patients per day in given mix

Please fill in orange cells

		Minutes
	Potential exam time per day (12h)	720
minus	Non-Availability (equals to 2h fixed ready to measure time)	120
	Available potential scanning time	**600**

Product

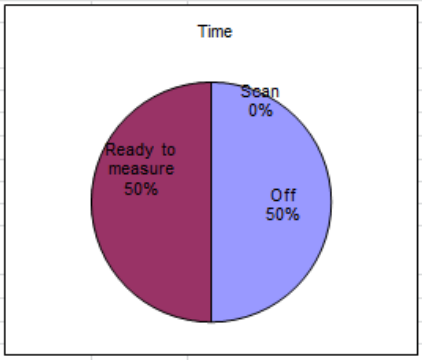
Product category

Start	Action	End	Duration	Distribution	Normalized	Min per day	optimized patients that can be treated within this timeshare	scan
0:00:00	average head examination total	0:00:00	0:14:21	25	24%	143	9,955	00:0
0:00:00	typical spine measurement (lumbar spine)	0:00:00	0:13:41	26	25%	149	10,858	00:0
0:00:00	typical abdomen measurement	0:00:00	0:22:43	25	24%	143	6,289	00:0
0:00:00	typical knee measurement	0:00:00	0:14:10	20	19%	114	8,067	00:0
0:00:00	typical angio measurement	0:00:00	0:16:17	9	9%	51	3,158	00:0
				105	1,0000	600	**38,327**	

	Time in Min	kW	kWh
Energy for non-availability (2h for service, reliability etc. in which system is ready to measure) ***fixed***	120		0,00
Off -time (12h) ***fixed***	720		0

Per day:	Time min		Energy kWh
Off	720,00	0,00	0,00
Ready to measure	720,00	0,00	0,00
Scan	0,00	#DIV/0!	0,00
Sum of Energy per day for max. exams in given distribution	**1440,00**	**0,00**	**0,00**

Average kWh/Patient **0,00**



Power consumption in service/diagnostic and ready-to-scan mode

APPENDIX I

MRI CONFIGURATION

List of parameters[1] to be used to configure the MRI for each specific sequence.

HEAD	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration	Leitlinien BAEK 2000.pdf	
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK	Table	Subtopic
localizer	1		280x280	240		8	6		1,1	0,6	83,3	290			
t2_tirm_tra_dark-fluid_320	28	≤ 250	230 x 200	220x220	≤ 6	5	5	≤1	0,8	0,7	31,3	191	< 00:05:00	Tabelle 2	Schädel
t2_tse_sag_512	27	200..250	250 x 225	220x220	5..6	5	5	≤1	0,5	0,5	195	31,3	< 00:05:00	Tabelle 1a	
ep2d_diff_3scan_trace_p2	23	≤ 250	240	210		5	5	≤1	1,9	1,2	1305	250,0	< 00:05:00	Tabelle 2	MRA
t1_se_tra_320	28	200..250	230 x 230	220x220	5..6	5	5	≤1	0,9	0,4	163	25	< 00:05:00	Tabelle 1a	
t1_se_tra_320	28	200..250	230 x 230	220x220	5..6	5	5	≤1	0,9	0,4	163	25	< 00:05:00	Tabelle 1a	
t1_se_cor_320	32	200..250	230 x 230	220x220	5..6	5	5	≤1	0,9	0,4	163	25	< 00:05:00	Tabelle 1a	

SPINE	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration	Leitlinien BAEK 2000.pdf	
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK	Table	Subtopic
localizer	5		450x450	240		8	8		1,8	0,6	290	83,3			
t2_tse_sag_512	16	≤ 350	300x300	260	≤ 4	4	3	≤1	0,8	0,5	244	41,67	< 00:05:00	Tabelle 2	BWS/LWS
t1_tse_sag_512	15	≤ 350	300x300	260	≤ 4	4	3	≤1	0,8	0,5	250	62,5	< 00:05:00	Tabelle 2	BWS/LWS
t2_tse_tra_512	20	≤ 350	230 x 230	150x150	≤ 4	4	4	≤1	0,7	0,4	195	250	< 00:05:00	Tabelle 2	BWS/LWS
t1_tse_tra_448	20	≤ 350	230 x 230	150x150	≤ 4	4	4	≤1	0,7	0,4	228	25	< 00:05:00	Tabelle 2	BWS/LWS

ABDOMEN	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration	Leitlinien BAEK 2000.pdf	
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK	Table	Subtopic
localizer	5		500x500	380		8	6,0	1,7	2,0	0,989583	450	83,3			
t1_fl2d_opp-in_tra_p2_mbh	30	300..400	380	330x350	≤ 6	6	6	≤ 2	1,5	1,1875	977	83,3	< 00:00:45	Tabelle 1b	
t2_trufi_cor_p2_bh	25	300..400	400	350x300	≤ 6	6	5	≤ 2	1,4	1,0	651	125	< 00:05:00	Tabelle 1b	
t2_tse_tra_p2_mbh_320	30	300..400	380	330x350	≤ 6	6	5	≤ 2	1,2	1,1	651	62,5	< 00:05:00	Tabelle 1b	
t1_vibe_fs_tra_p2_320_bh_pre	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45	Tabelle 1b	
t1_vibe_fs_tra_p2_320_bh_arterial	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45	Tabelle 1b	
t1_vibe_fs_tra_p2_320_bh_venous	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45	Tabelle 1b	
t1_vibe_fs_tra_p2_320_bh_delayed	64	300..400	400	330x350	≤ 6	4	3	≤ 2	1,25	1,1	488	166,7	< 00:00:45	Tabelle 1b	
t1_vibe_fs_cor_p2_bh_288_post	128	300..400	400 x 345	350x315	≤ 6	4	1,6	≤ 2	1,4	1,1	600	166,7	< 00:00:45	Tabelle 1b	

KNEE	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration	Leitlinien BAEK 2000.pdf	
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK	Table	Subtopic
localizer_tra	3		500x500	280		8	5		2,0	0,7	250	83,3			
localizer_sag+cor+tra	3		350	215x231		8	5		1,4	0,7	250	83,3			
t1_se_sag_512	32	≤ 250	160 x 160	160x160	3,0	4	3	≤ 0,5	0,5	0,3	244	31,25	< 00:07:00	Tabelle 2	Kniegelenk
t2_tse_fs_sag_320	30	≤ 250	160 x 160	160x160	3,0	4	3	≤ 0,5	0,5	0,5	244	41,67	< 00:07:00	Tabelle 2	Kniegelenk
pd_tse_fs_cor_p2_512	30	≤ 250	160 x 160	140	3,0	4	3	≤ 0,5	0,5	0,3	195	41,67	< 00:07:00	Tabelle 2	Kniegelenk

ANGIO	Slices	FoV / mm x mm			Slice thickness / mm			Resolution / mm			Bandwidth / Hz/Px		Sequence duration	Leitlinien BAEK 2000.pdf	
	S/P	BÄK	Max	Min	BÄK	Max	Min	BÄK	Max	Min	Max	Min	BÄK	Table	Subtopic
I Localizer feet	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244			
II Localizer legs	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244			
III Localizer upper legs	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244			
IV Localizer abdomen	7		500x500	400 x 400		8,0	7		2,0	1,6	558	244			
IV_Angio3D_abdomen_pre	96	≤ 400	400 x 350	330x350		2,6	1,3	≤ 2	1,4	1,1	680	488	< 00:05:00	Tabelle 2	V. cava
III_Angio3D_upper_legs_pre	96	≤ 500	400 x 350	330x350		2,6	1,3	≤ 2	1,4	1,1	680	488	< 00:05:00	Tabelle 2	Extremitätengefäße
II_Angio3D_legs_pre	88	≤ 500	400 x 350	330x350		2,2	1,1	≤ 2	1,3	1,0	690	488	< 00:05:00	Tabelle 2	Extremitätengefäße
I_Angio3D_feet_pre	96	≤ 500	400 x 350	330x350		2	0,9	≤ 2	1,3	0,9	490	488	< 00:05:00	Tabelle 2	Extremitätengefäße
IV_Care_bolus	1		450 x 365	330x350		20,0			1,8		400				
IV_Angio3D_abdomen	96	≤ 400	400 x 350	330x350		2,6	1,3	≤ 2	1,4	1,1	680	488	< 00:01:00	Tabelle 2	V. cava
III_Angio3D_upper_legs	96	≤ 500	400 x 350	330x350		2,6	1,3	≤ 2	1,4	1,1	680	488	< 00:01:00	Tabelle 2	Extremitätengefäße
II_Angio3D_legs	88	≤ 500	400 x 350	330x350		2,6	1,1	≤ 2	1,3	1,0	690	488	< 00:01:00	Tabelle 2	Extremitätengefäße
I_Angio3D_feet	96	≤ 500	400 x 350	330x350		2	0,9	≤ 2	1,3	0,9	490	488	< 00:01:00	Tabelle 2	Extremitätengefäße

[1] *The parameters have been defined according to the German "Guidelines of the Federal Medical Council for Quality Assurance of magnetic resonance imaging" (BAK) and the "guidelines on criteria for quality assessment in nuclear magnetic resonance imaging pursuant to § 136 SGB V i.V.m. § 92 SGB V, Section 1 of the Federal Committee of Physicians and Sickness Funds (Quality assessment guidelines for magnetic resonance imaging).*