The Determination Of The Exposure To Electromagnetic Fields In Aluminum Electrolysis

R. Von Kaenel, J.P. Antille
Alusuisse-Lonza Services Ltd., CH-3965 Chippis

A.F. Steinegger
Health and Safety Consultant, CH-3973 Venthône

Abstract

The possible biological and health effects of magnetic fields are the subject of controversy. The discussion has not yet yielded a conclusive answer. In such a situation it is important to have exposure data of the personnel to compare them with existing limit values and the general exposure in daily life. This study analyses the results of measurements performed in a potroom of an aluminum smelter with an amperage of 103'000 A direct current. Direct current is always superposed with oscillating currents. Therefore the magnetic fields of these alternating current components have also been determined.

The evaluation of both types of measurements shows that, according to present knowledge, exposure in an aluminum smelter with an amperage of 103'000 A causes no health risk.

Introduction

The question of possible health risks arising from electromagnetic fields has become a topical issue because of articles published in newspapers, magazines and popular scientific publications. There is no conformity of opinion as to the biological and health effects of magnetic fields. This controversial question was the subject of about 1000 articles published by scientists within the last 15 years. 1)

A series of recently published articles tries to give an answer to the question "Electric and magnetic fields : What do we know ?" as a follow-up to a major theme of discussion at the 1991 American Industrial Hygiene Conference and Exposition. 2)

In these five publications, it is pointed out that exposure assessment is important for scientific investigations to understand better the dose-related health effects and as a base for future epidemic studies. 3)-7)

Measurements of electromagnetic fields in the smelter

Two types of measurements were performed. First the stationary induction magnetic field was measured, that is to say the part of the induction magnetic field which does not depend on time. The stationary induction magnetic field is often called the steady magnetic field, static magnetic field or even the constant magnetic field, although it varies strongly in space. Secondly the time-dependent induction magnetic field was measured. In this case it is of great interest to consider the magnetic field as a superposition of alternative magnetic fields within different frequencies and amplitudes. The amplitude of the signal decreases quickly as the frequency increases. The significant amplitudes are searched for a given range of frequencies.

Stationary magnetic fields

By a rough estimation a magnetic induction of 20 mT (200 Gauss) can be expected at a distance of 1 meter from the main current conductor of a smelter with 100'000 A direct current. At different locations in a typical working area, at distances of 2-5 m from the conductor, 10-4 mT can be expected. More detailed information about exposure of the work force can be obtained by stationary measurements in the working area and by personal monitoring.

Stationary measurements

First a simple Gauss-meter was used for the measurements. The points to measure around the pots are plotted on Fig. 1.

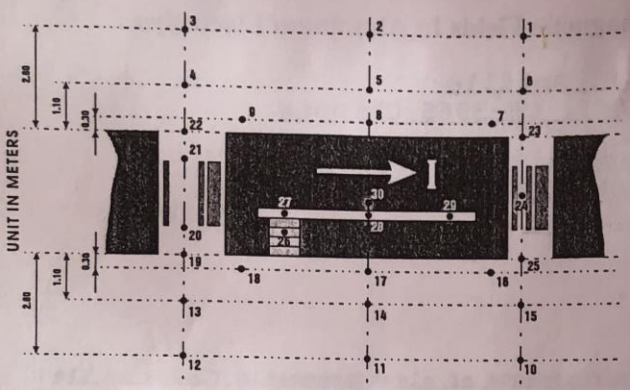

Fig. 1 : Location of the measurements of the stationary induction magnetic field around the cell

The distance was 1 m (3.3 feet) above the ground level with the exception of points 26-30. There the values taken are that of a man standing on the hooding cover of the pot. The measured values of three pots are put together in Tab. 1. The mean value can be considered as a good approximation of the situation around the pots.

	POT			
Pos.	No. 5	No. 7	No. 9	Mean
1	0.93	0.87	0.84	0.88 ± 0.05
2	0.92	0.83	0.80	0.85 ± 0.06
3	0.89	0.87	0.76	0.84 ± 0.07
4	1.19	1.48	1.12	1.26 ± 0.19
5	1.15	0.96	0.96	1.02 ± 0.11
6	1.31	1.44	1.19	1.31 ± 0.13
7	2.18	2.54	2.42	2.38 ± 0.18
8	1.55	1.44	1.75	1.58 ± 0.16
9	2.65	2.40	2.49	2.51 ± 0.13
10	2.49	2.43	2.64	2.51 ± 0.11
11	2.25	2.47	2.76	2.49 ± 0.26
12	2.46	2.57	2.56	2.53 ± 0.06
13	2.76	2.76	3.05	2.86 ± 0.17
14	2.36	2.69	2.48	2.51 ± 0.17
15	2.35	3.13	2.81	2.76 ± 0.39
16	2.77	2.85	2.87	2.83 ± 0.05
17	2.27	2.13	2.36	2.25 ± 0.12
18	3.79	3.67	4.05	3.84 ± 0.19
19	4.63	4.21	4.24	4.36 ± 0.23
20	6.34	8.62	6.89	7.28 ± 1.19
21	5.21	8.06	5.74	6.34 ± 1.52
22	4.15	3.38	1.48	3.00 ± 1.37
23	7.35	3.55	2.43	4.44 ± 2.58
24	10.87	5.98	12.32	9.72 ± 3.32
25	8.13	4.76	4.22	5.70 ± 2.12
26	5.54	6.60	7.06	6.40 ± 0.78
27	5.12	5.91	7.85	6.29 ± 1.40
28	3.31	3.95	4.18	3.81 ± 0.45
29	1.29	1.60	1.85	1.58 ± 0.28
30	1.79	2.19	2.21	2.06 ± 0.24

Tab. 1: Stationary measurement of static electromagnetic fields in potroom: results and mean values [mT] of three measurements.Position of the measured points: see Fig. 1

Personal monitoring

Personal monitors for stationary magnetic fields are not yet commercially available. For that reason we used as dosimeter a prototype probe analyzer built according to specifications by Aluminiumindustriens Miljøskretariat / University of Oslo, which has kindly been made available to us. The system is mainly composed of the following elements:

- A GRANT Model 1203 data acquisition system protected by a shielding box.
- A box containing three Hall effect F.W. Bell magnetic probes, one for each component of the induction magnetic field, and an amplifier.

The readings of the three Hall effect probes are recorded in the shielding box. A calibration of the system was performed in situ, that is to say in the potroom. The aim was to check wether the data logger and/or the amplifier were correctly shielded. The reference measurements were performed with a Bell 4048 Gauss-meter which was itself calibrated with a reference magnet. The data acquisition readings were correlated to the reference measurements. The range of possible measurements of the data acquisition system varies from 0.0-90.0 mT (0 to 900 Gauss) and the sensitivity is about 3 mV/0.1 mT. The overall precision of one measurement is better than +- 0.2 mT which is good enough for the determination of the mean stationary induction magnetic field.

We would like to thank specially Mr. E. Wolff from the AMS Aluminiumindustriens Miljøsekretariat, Oslo, Norway for having kindly accepted to perform some measurements at our plant using their own data acquisition system. This has allowed us to cross-check some of our measurements.

With the dosimeter, the electromagnetic field components Bx,By,Bz can be measured in the three coordinates x, y and z. In combination with a data logger it is possible to get data for longer periods. The resulting magnitude B of the magnetic induction for each measurement is:

$$B[mT] = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

Test run

After some stationary measurements in comparison with another instrument, the probe analyzer for personal sampling was tested over a period of 36 minutes. The graph of the more than 2000 values measured in the potroom (one data point every two seconds) is presented in Fig. 2.1 and Tab. 2.

This test run included movements to all possible locations, also those to which a worker never, or only occasionally, has to go during his daily shift. The values of this test run do not reflect the exposure of a worker doing his normal job.

	Test mT	Shift mT
$B_{max} = \sqrt{B_x^2 + B_y^2 + B_z^2}$	40.9	53.0
$\overline{B}_{RMS} = \sqrt{(\frac{\sum B_x^2+B_y^2+B_z^2}{n})}$	7.3	4.4
$\overline{B} = \frac{\sum\sqrt{B_x^2+B_x^2+B_x^2}}{n}$	4.4	3.3

Tab. 2: Exposure to static electromagnetic fields, data registered from a dosimeter for personal monitoring: test run (36 min) and shift period (7 ¼ hours). In the column 'data' the number of measurement in the corresponding range is indicated. The following column gives the percentage ratio of all measurement.

	test run		Shift	
Range [mT]	Data	%	Data	%
1-2	29	2.67	4011	31.47
2-3	17	1.56	1434	11.25
3-4	85	7.81	1388	10.89
4-5	212	19.50	978	7.67
5-6	214	19.69	1353	10.62
6-7	88	8.10	1241	9.73
7-8	56	5.15	976	7.66
8-9	86	7.91	541	4.25
9-10	88	8.10	341	2.76
10-11	68	6.26	120	0.94
11-12	26	2.39	77	0.60
12-13	12	1.10	34	0.24
13-14	10	0.92	34	0.27
14-15	3	0.28	21	0.17
15-16	2	0.18	24	0.19
16-17	8	0.74	8	0.06
17-18	4	0.37	18	0.14
18-19	2	0.18	6	0.04
19-20	3	0.28	3	0.02
Total	1087		12751	
0-10	931	85.64	12389	97.29
10-20	138	12.7	342	2.67
>20	18	1.65	20	0.16

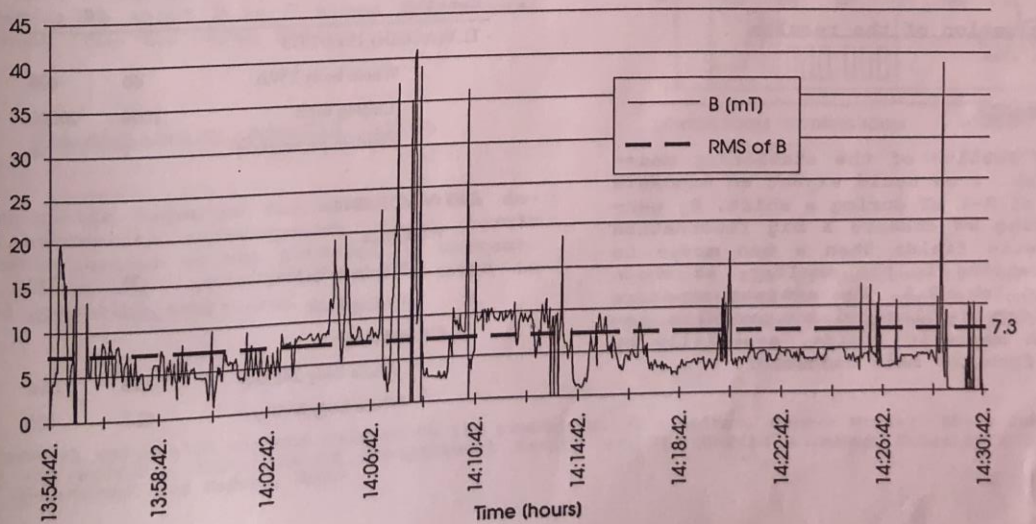

Fig. 2.1 : Recorded induction magnetic field to all possible locations around the cell.

Measurement during a shift

To determine a representative exposure of a worker during a shift nearly 13'000 data were recorded over a period of approximately 7 1/4 hours. They are summarized in Tab. 2.

Fig. 2.2 shows a typical signal for about two hours recorded with a personal monitoring system. The peak values are mesured when the operator crosses the line in between two end to end cells.

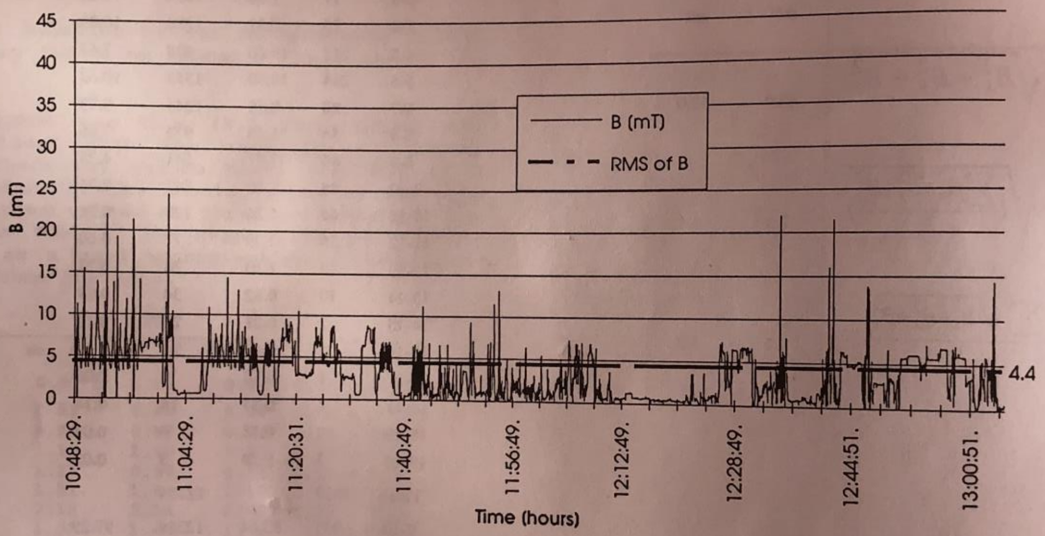

Fig. 2.2: Personal monitoring of the module of the steady state induction magnetic field during two hours of a pot operator shift.

Evaluation of the results

General statements

Following the results of the stationary measurements in Tab. 1 we could expect an exposure in the range of 2-4 mT during a shift. By personal monitoring we observe a big fluctuation for the magnetic fields when a man moves to different locations in the smelter, as shown in Fig. 2 and Tab. 2.1. The average exposure can be considerably lowered by avoiding regions of high magnetic fields, especially by keeping away from the main conductor.

Comparison with the limit values for occupational exposure

There exist different limit values for occupational exposure to electromagnetic fields. The actual threshold limit values of the American Conference of Governmental Industrial Hygienists (TLV ACGIH) 8) and the German prenorm DIN/V VDE 0848 9) (cf. Tab.3) are mostly applied. Older limits, as cited in 10), 11), were between 10-60 mT.

Tab. 3: Commonly used limit values for static magnetic fields for occupational exposure

Electromagnetic flux density	[mT]	Gauss [G]
TLV(ACGIH) 1992-1993		
Whole body TWA	60	600
Ceiling limit	2000	20000
Cardiac pacemakers	1	10
DIN /V VDE 0848		
Workplace		
Whole body, long time	75	750
Ceiling limit	2000	20000
General public		
Whole body 24h/day	1.26	12.6
Whole body 6h/day	12.6	126

In our measurements, the time-weighted averages (TWA) value of 60, resp. 75 mT over a whole shift is respected with an ample margin to spare. The exceptional high peaks are even lower than the limit values.
People with cardiac pacemakers are not allowed to enter the potroom.

Comparison with other data from industry and daily life

Published data on occupational exposure to static electromagnetic fields are rather rare. Measurements of static electromagnetic fields have been made in chlor-alkali production. Values from 0.1 to 18 mT are reported. 12) More publications concern the medical applications of electromagnetic field, for instance in magnetic resonance imaging, where fields strengths usually up to 2 T (20'000 Gauss) were used. In a particle accelerator used in basic physical research they can achieve a level of up to 3.5 T.

At a conference *G.Thommesen and P.S. Bjølset presented measured data for the exposure of workers in aluminum smelters in the range of 3-10 mT, which can go up to 50 mT occasionally. The geomagnetic field is 0.05 mT (0.5 Gauss).

If we calculate the natural dose we get in a lifetime of 75 years, this dose is about 3×10^4 [mT x hours] or 30×10^4 [Gauss x hours]. The expected dose for a man working in a smelter can be approximated for an occupation duration of 20 years with $10\text{-}20 \times 10^4$ [mT x hours] or $100\text{-}200 \times 10^4$ [Gauss x hours], which corresponds to about 3 to 7 times the natural background from the earth field.

Non-stationary magnetic fields

Usually static magnetic fields have time dependently components superimposed. These result from rectification of the alternating current. These fields have also been investigated in special measuring campaigns.

Description of the instrumentation

The measurements of the non-stationary induction magnetic field are more difficult than for the steady field, because the amplitude of the signals is much smaller, the spectrum of the frequencies is rather large and the measurement equipment must be carefully protected against mutual inductances. We have therefore contracted the firm EMC (ElectroMagnetic Compatibility) from Fribourg, Switzerland, specialized in such measurements, to analyze the situation. The spectrum of frequencies was analyzed from 0 to 5000 Hz. Different devices were used :

- TABOR Signal generator 0.01Hz - 50 MHz
- TRMS Multimeter-Frequencemeter 20Hz-10kHz
- SOLAR induction magnetic field probe 10Hz-100kH
- Air bobbin with 1500 loops 0 Hz - 50 Hz
- Helmholz bobbin for calibration
- Numerical oscilloscope with FFT option

The Fast Fourier Transform (FFT) is a mathematical method which will determine the amplitude of the most significant frequencies.

The measurements can be subdivided into three regions as shown in Fig. 3.

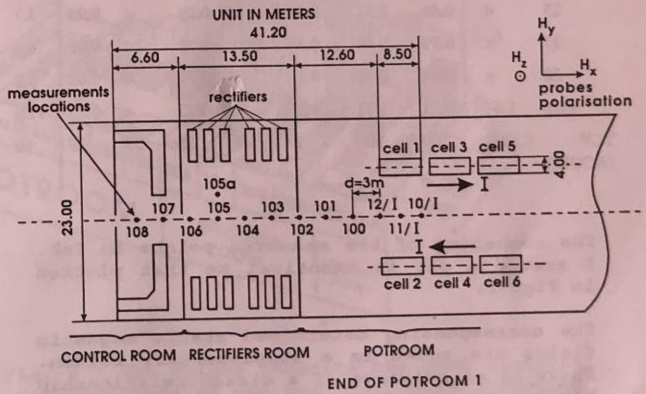

Fig. 3 : End of potroom 1. The symbols show the locations of the non-stationary induction magnetic field measurements performed 1 meter

*Environmental and health aspects related to the production of aluminum, Bergen Norway, 28-30 June 1993, organized by the National Institute of Occupational Health and The Nordic Aluminum Industry's Secretariat for Health, Environment and Safety, Oslo.

Tab. 5: Stationary measurement of superposed oscillating current from 50 to 2400 Hz around pot No. 1 (see also Fig. 1). These data are completed with the corresponding values for static magnetic fields (mean values from Tab. 1).

Pt. (No)	[Hz]								
	50	300	600	1200	1500	1800	2100	2400	dir. cur.
				B [µT]					B [mT]
1	<	0.62	0.35	0.08	<	0.07	<	0.03	0.9
2	<	1.02	0.51	0.12	<	0.15	<	0.06	0.9
3	<	2.62	1.26	0.28	0.15	0.44	<	0.14	0.8
8	<	0.94	0.55	0.17	<	0.22	<	0.09	1.6
10	<	0.45	0.18	0.14	<	0.08	<	0.02	2.5
11	<	0.72	0.37	0.18	0.05	0.17	<	0.05	2.5
12	1.64	2.23	1.00	0.21	0.16	0.35	<	0.09	2.5
17	<	0.76	0.41	0.15	0.04	0.15	<	0.06	2.3
22	<	3.31	1.70	0.54	0.19	0.75	0.13	0.35	3.0
23	<	0.66	0.20	0.21	<	0.10	<	0.02	4.4
24	1.53	1.06	0.39	0.45	<	0.17	<	0.08	9.7
25	<	0.44	0.21	0.18	<	0.09	<	0.03	5.7
27	<	0.79	0.49	0.34	0.09	0.28	<	0.09	6.3
28	<	0.64	0.43	0.10	<	0.17	<	0.07	3.8
Max	1.64	3.31	1.71	0.54	0.54	0.75	<	0.35	11.3
TLV (ACGIH)	1200	200	100	50	40	33	29	25	60

The numbering of the measured points in Tab. 5 around a pot is identical to that plotted in Fig. 1.

The corresponding determined static magnetic fields are added in a supplementary column. There is no evidence of a direct relationship between the magnitude of static and alternative magnetic fields. In contrast, we see a marked diminution of the values with increasing distance from the rectifier, as illustrated also in Fig. 4.

Evaluation of the results

As can be observed in Tab. 4, all measured values are below the limit TLV (ACGIH) for the different frequencies, even for the maximum values. The ratio of these to the limit values ranges between 1/6 to 1/200. If we compare the range of the measured values in relationship with different exposure limits (Fig. 5), we do not find any measurement which surpasses the limit even for non-occupational exposure. In addition, the highest values are found at locations where personnel in the potroom normally do not to stay. The alternating electromagnetic fields around the pots are even much lower.

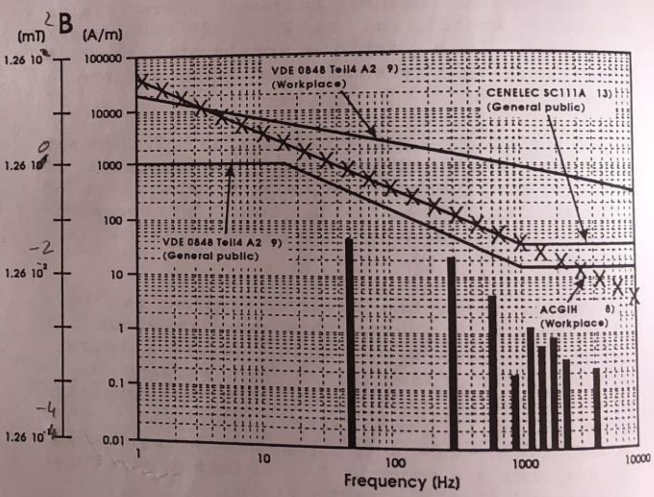

Fig. 5: The colums indicate the range of measurements at all locations given in tables 4 and 5. Only 50 Hz, 300 Hz up to 2400 Hz by steps of 300 Hz have a measurable magnitude. The upper measured values are much lower than the four standards limit values.

above the ground going from the control room through the rectifier room into the potroom.

In Tab. 4 the measured values of these measurements are put together for the frequency of 50, 300 and by steps of 300 Hz up to 2400 Hz. At the bottom of the table the maximum value of each frequency and the corresponding frequency-dependent limit value (TLV/ACGIH) are indicated.

Tab. 4: Stationary measurement of superposed oscillating currents from 50 to 2400 Hz in the potroom, rectifier and control room (see also Fig. 3).

Pt. (No)	[Hz] 50	300	600	1200	1500	1800	2100	2400
	B[µT]							
Pot								
10/1	<	0.45	0.18	0.14	<	0.08	<	0.02
11/1	<	0.72	0.37	0.18	0.05	0.17	<	0.05
12/1	1.64	2.23	1.00	0.21	0.16	0.35	<	0.09
100	3.95	6.02	2.33	<	0.34	0.48	0.06	<
101	6.43	8.20	3.36	<	0.40	0.63	0.10	<
102	12.85	14.79	6.05	<	0.62	1.05	0.14	<
Rectifier								
103	46.14	19.5	4.73	1.19	0.66	0.60	0.14	0.30
104	47.78	7.24	2.70	1.27	0.19	0.34	<	0.33
105	45.75	14.02	2.86	1.43	0.40	0.27	0.14	0.30
105a	55.27	30.61	4.41	1.72	0.78	0.06	0.06	0.44
106	41.04	11.67	4.79	1.19	0.14	0.41	0.09	0.32
Control								
107	14.45	4.76	2.00	0.16	0.14	0.20	0.06	0.05
108	7.84	1.27	0.90	0.07	0.03	0.05	0.02	0.03
Max. val.	55.3	30.6	4.7	1.43	0.78	1.05	0.14	0.44
Limit val. (ACGIH)	1200	200	100	50	40	33	29	25

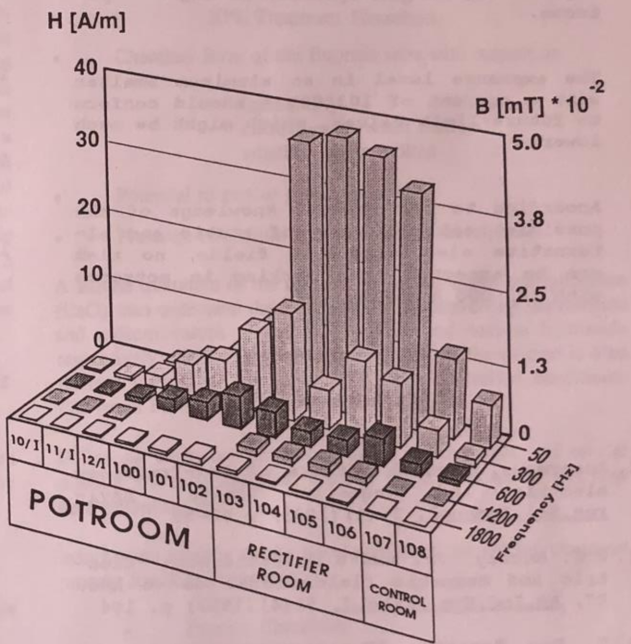

Fig. 4 : The colums indicate the most significant magnitude of the non stationary induction magnetic field going from the control room, through the rectifier room into the potroom. The non-stationary field has a discrete spectrum (50,300,600,1200,1800 Hz) and almost vanishes close to the cell.

Conclusions

- The occupational exposure to static magnetic fields in an aluminum smelter of 103'000 A is well below the TLV (ACGIH) of 60 mT. For routine work it is less than 10% of the limit.

- The appearance of oscillating alternating current components could be demonstrated for frequencies of 50 up to 2400 Hz. The magnitude of these fields is very low and rapidly decreases with the distance from the rectifier room. It is therefore of no significance for the worker in the potroom.

- The exposure level in an aluminum smelter with a current of 103'000 A should conform to future limit values, which might be much lower.

- According to our present knowledge of the possible health effects of static and alternative electromagnetic fields, no risk can be expected from working in potrooms with 103'000 A cells.

References

1. Anonymous, "Health effects of low-frequency electric and magnetic fields" Environ.Sci.Technol. 27(1)(1993) p 42-58

2. W.E. Murray, Jr. and R.M. Patterson: "Electric and magnetic fields: What do we know ?", Am.Ind.Hyg.Assoc.J. 54(4)(1993) p. 164

3. T. Dan Bracken, "Exposure assessment for power frequency electric and magnetic fields", Am.Ind.Hyg.Assoc.J. 54(4)(1993) p. 165-177

4. St.F. Cleary, "A review of in vitro studies: Low-frequency electromagnetic fields", Am.Ind.Hyg.Assoc.J. 54(4)(1993) p. 178-185

5. L.E. Anderson, "Biological effects of extremely low-frequency electromagnetic fields: In vivo studies", Am.Ind.Hyg.Assoc.J. 54(4)(1993) p. 186-196

6. D.A. Savitz, "Overview of epidemiologic research on electric and magnetic fields and cancer", Am.Ind.Hyg.Assoc.J. 54(4)(1993) p. 197-204

7. W.E. Feero, "Electric and magnetic field management", Am.Ind.Hyg.Assoc.J. 54(4)(1993) p. 205-210

8. American Conference of Governmental Industrial Hygienists, 1992-1993 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices (Cincinnati, OH: American Conference of Governmental Industrial Hygienists, 1992)

9. DIN Deutsches Institut für Normierung und Verband Deutscher Elektrotechniker (VDE) e.V. "Sicherheit in elektromagnetischen Feldern, Grenzwerte zum Schutz von Personen im Frequenzbereich von 0 Hz bis 30 kHz", Änderung 2, DIN/V VDE 0848, Teil 4 A2 (Berlin, FRG: Beuth Verlag GmbH), Dezember 1992

10. World Health Organization, "Magnetic Fields", Environmental Health Criteria 69 (Geneva: World Health Organization, 1987).

11. G. Miller, "Exposure guidelines for magnetic fields" Am.Ind.Hyg.Assoc.J. 48(12)1987) p. 957-968

12. H. Pastides et al. "A characterization of occupational static magnetic field exposures at a diaphragm-cell and a mercury-cell chlor alkali facility" Appl.Occup.Environm.Hyg 7(1)(1992) p. 42-48

13. European Committee for Electro Technical Standardisation (CENELEC) CLC/ SC111A (SEC6) "Human exposure to electromagnetic fields: Low frequency fields" April 1993

Conclusions

- The occupational exposure to static magnetic fields in an aluminum smelter of 103'000 A is well below the TLV (ACGIH) of 60 mT. For routine work it is less than 10% of the limit.

- The appearance of oscillating alternating current components could be demonstrated for frequencies of 50 up to 2400 Hz. The magnitude of these fields is very low and rapidly decreases with the distance from the rectifier room. It is therefore of no significance for the worker in the potroom.

- The exposure level in an aluminum smelter with a current of 103'000 A should conform to future limit values, which might be much lower.

- According to our present knowledge of the possible health effects of static and alternative electromagnetic fields, no risk can be expected from working in potrooms with 103'000 A cells.

References