Utveckling & Miljö

1988-04-29

PROJEKT RADON
LÄGESRAPPORT JAN. 1988
Sammanfattning

Projektet började sin verksamhet i mitten av mars 1987 med målsättningen att genomföra radonundersökningar i 2000 vattenfallsanställdas bostäder samt att fortsätta att bidra till radonfilterutvecklingen. Projektet medverkar till att utveckla metoderna för radonmätning och sanering samt att anpassa metoderna för storskalig tillämpning.

Projektet som indelats i tre delprojekt skall vara avslutat under 1989. Tidplanen har hittills kunnat följas. Kostnadsramen för projektet har däremot ökats huvudsakligen beroende på redovisningssättet för egna personalens lönekostnader och ökade kostnader för mätutrustningen.

Hittills har genomförts ca 400 s.k. radonspårningsmätningar (grovmätning) och ett tiotal åtgärdsmätningar (saneringsmätning). Fyra högradonvillor har åtgärdats.

Erfarenheten visar att vår mätmetodik är fullt användbar och att rekommenderade saneringsåtgärder ger fullgott resultat.

Det kan också konstateras att flertalet av hus med hög radonnivå har dålig ventilation och många har såväl fukt som mögelproblem.

Intresset för radonprojektet är stort även utanför de tre delprojekten.

Arbetet under 1988 och 1989 kommer utöver mätningarna att inriktas på förbättring av mätmetoderna. En åtgärdskatalog skall tas fram i samarbete med ventilationsföretag.

Sam Ekholm, PKK

Vattenfall

PROJEKT RADON

Lägesrapport jan 1988, Arbetsprogram för 1988 och 1989

1 Arbetsläge

Projektet beslutades i december 1986.

Projektorganisationen började sin verksamhet i mitten av mars 1987. Projektet indelades i tre delprojekt med en central projektledare i Stockholm. En ledningsgrupp formerades. Arbetet
./. indelades i följande etapper: (Se även tidplan bil. 1).

Etapp 1 — Materialanskaffning
4 mätvagnar utrustade med radonmätare, mätutrustning för luftomsättningsmätning utrustning för saneringsmätning m.m. levererades i slutet på 1987.

Etapp 2 — Framtagning av principer och anvisningar för mätningarna. Utbildning av mätpersonal. Information till fastighetsägare, allmänhet, myndigheter och massmedia.
Utbildning har genomförts på tre orter: Storuman, Ringhals och Forsmark, sammanlagt deltog ca 40 personer i utbildningen.
Berörda myndigheter har informerats genom informella möten på Vattenfall. En presskonferens där projektet presenterades har hållits.
Kontaktbehovet internt och externt växer kontinu-
./. erligt. En adress- och telefonlista (se bil. 2) har tagits fram för att underlätta kontakter med projektet och övriga berörda.

Etapp 3 — Grovmätning. Att med hjälp av radonmätare bestämma radondotterhalten i några rum i fastigheten som skall undersökas.
Grovmätning har påbörjats i Storuman och i Ringhals.

Etapp 4 — Saneringsmätning. Att med speciellt tilluftaggregat påverka luftomsättningen i en fastighet. Mätningen klargör bl.a. om det är fråga om byggradon eller markradon. I mätproceduren ingår också specialmätningar för att lokalisera inträngningsställen för markradon. Förslag till saneringsåtgärder föreslås. Saneringsmätningar har påbörjats i Storuman och Ringhals.

Etapp 5 Forskningsverksamhet för vidareutveckling av radonfiltreringsutrustning.
Etapp 5 pågår i samarbete med Danmarks Tekniska Högskola och Tammerfors Tekniska Högskola.
./. Lägesrapport XIII, se bil. 3.

2 Kostnadsläge

Projektet har under 1987 förbrukat ca 2300 kkr. Bundna ännu inte utbetalda kostnader uppgår till ca 600 kkr.

Projektbeslutet i december 1986 som baserades på vissa förutsättningar slutade på 3,5 Mkr. En ny kostnadsberäkning visar att kostnaderna för projektet kommer att väsentligt överstiga den beslutade kostnadsramen om projektet skall genomföras med oförändrad omfattning.

En jämförelse av projektkalkylen 1986 och den nya bedömningen framgår av nedanstående sammanställning.

	Beslut kkr	Ny bedömning kkr	Anm.
Projektledning och adm.		1 340	
	1 300		1
Mätningar		1 620	
Mätutrustning	800	1 800	2
Utbildning	100	240	3
Forskning	1 250	1 250	
TOTALT	3 450	6 250	

./. Den reviderade budgetårsfördelningen framgår av bilaga 4.

1 I ursprungskalkylen antogs att medverkande strålskyddspersonal från Ringhals och Forsmark endast till en ringa del skulle belasta projektet enär de endast skulle utnyttjas under perioder med låg sysselsättningsgrad på ordinarie arbetsplats. Kostnadsökningen här är ingen reell kostnadsökning för Vattenfall men väl en omfördelning mellan olika resultatenheter.

2 Ursprungligen avsågs att inköpa 4 mätvagnar till en kostnad av 200 kkr per styck. En av vagnarna är stationerad i Stockholm de resterande på var sin mätplats. Vagnarna har dels blivit dyrare än beräknat, dels har utrustningen i vagnarna utökats för att effektivisera mätsekvensen. Det har bl.a. upphandlats ytterligare två radonmätare till vardera mätplatsen. Projektet förfogar nu över 10 radonmätare mot planerade 4.

3 Utbildningen delades upp på 3 omgångar i stället för 2 i projektkalkylen. Kostnaderna för informations- och upplysningsverksamheten har kraftigt underskattats. Löner för kursdeltagarna ingick inte heller i beslutskalkylen.

3 Resultat och erfarenheter

Grovkartläggningen har visat ta längre tid än beräknat huvudsakligen beroende på att informationen till fastighetsägare kräver mycket tid. I Ringhals har man övergått från ensamarbete till team om 2 man. Medan den ene mäter intervjuar och informerar den andre husägaren.

I villabebyggelse kan ca 4 hus mätas per dag och person. I radhus och lägenheter kan antalet ökas till 6. För att demonstrera mäthastigheten genomfördes under hösten 1987 ett pilotprojekt i samarbete med hälsovårdsnämnden i Storuman. Under en vecka mättes 96 villor av 4-6 man.

Hittills har utförts 181 grovmätningar i Storuman och 220 grovmätningar i Ringhals.

Intresse för radonmätningar har anmälts av 50% tillfrågade i Ringhals. Motsvarande för Storuman är närmare 100%.

Saneringsmätning utföres av tvåmannalag. Med nu tillämpad mätprocedur kan högst 4 saneringsmätningar utföras per vecka och lag.

Saneringar har genomförts i 2 högradonhus som försetts med Sv. Fläkt AB MAXI-aggregat varav ett med nolltrycksreglering. Åtgärderna har varit så pass lyckade att radondotternivåerna nu understiger 100 Bq/m^3.

Erfarenheterna från år 1987 utförda arbetet som givetvis skall beaktas i det fortsatta arbetet kan sammanfattas enligt nedan

- flertalet hus med hög radonnivå har dålig ventilation och många har såväl fukt som mögelproblem.

- informationen till fastighetsägaren om radonets risker och möjliga saneringsåtgärder är mera tidskrävande än vi räknade med.

- rationell grovmätning är möjlig endast vid samarbete med kommunala instanser.

- det har visat sig att de kommunalt ansvariga ofta är dåligt informerade i radonfrågan.

- intresset för radonprojektet är stort även utanför de tre delprojektområdena.

- massmedias bevakning av radonfrågan är av största betydelse för spridning av informationen till allmänheten. Intresset från massmediernas sida är ökande.

4 Arbetsprogram för 1988 och 1989

Den övergripande målsättningen för Vattenfalls radonsatsning är bl.a. att vidareutveckla metoderna för radonmätning och sanering samt att anpassa metoderna för storskalig tillämpning.

Materialanskaffning

Antalet radonmätare är nu tio. Ytterligare kompletteringar kommer inte att ske. Mindre kompletteringar av fläktsatser för att effektivisera saneringsmätningen erfordras.

Utbildning och information

En ny informationsbroschyr "Radon hemma" skall tas fram under våren 1988. Den presenterar i korthet risker, våra mätmetoder och våra åtgärdsförslag.

Ett filmföretag är mycket intresserad att göra en informationsfilm om radon. Deras förslag till manus är intressant för oss och vi bör medverka.

Önskemål om fortsatt utbildning av Vattenfalls personal har framförts. Även externt, kommunens olika befattningshavare, konsulter och tillverkare av ventilationsutrustning har önskat fortsatt utbildning. Nya kurser kommer att anordnas under 1988. Finansiering genom deltagaravgifter. Det har framförts flera önksemål om föredrag och annan extern information till allmänhet och till myndigheter. Informationsträffar med berörda myndigheter 2 ggr/år kommer att fortsätta.

Grovkartläggning

Grovkartläggningen fortsätter enligt plan.

Kostnaden för hittills utförda mätningar är högre än de kalkylerade. Samtliga delprojekt skall försöka utveckla mättekniken så att de kalkylerade kostnaderna kan uppnås åtminstone under några kampanjveckor.

Tammerfors Tekniska Högskola hävdar i en rapport att Studsviks radonmätare kan missvisa upp till 40% vid extremt torr luft. Fortsättningsvis skall fukthalten kontrolleras inomhus vid grovkartläggningen. Tillförlitligheten hos vår grovkartläggning skall kontrolleras genom jämförelse med långtidsmätning i 30 hus i Storuman under våren 1988. Studsvik skall ta fram en metod för fältkontroll av mätarens funktion. Den noggrannare årliga kalibreringen av instrumentet förbättras. Korsvis kalibrering skall provas mellan SSI, TTH och DTH.

Utbytessystem för mätare skall införas, dvs. att skadad mätare skall under reparationen ersättas med ett reservinstrument.

En kartläggning av i marknaden befintliga mätare skall genomföras. Provexemplar av några intressanta typer bör anskaffas.

Saneringsmätning, saneringsåtgärder

Saneringsmätning fortsätter enligt plan.

En snabbare saneringsmätningsmetod skall utvecklas under 1988.

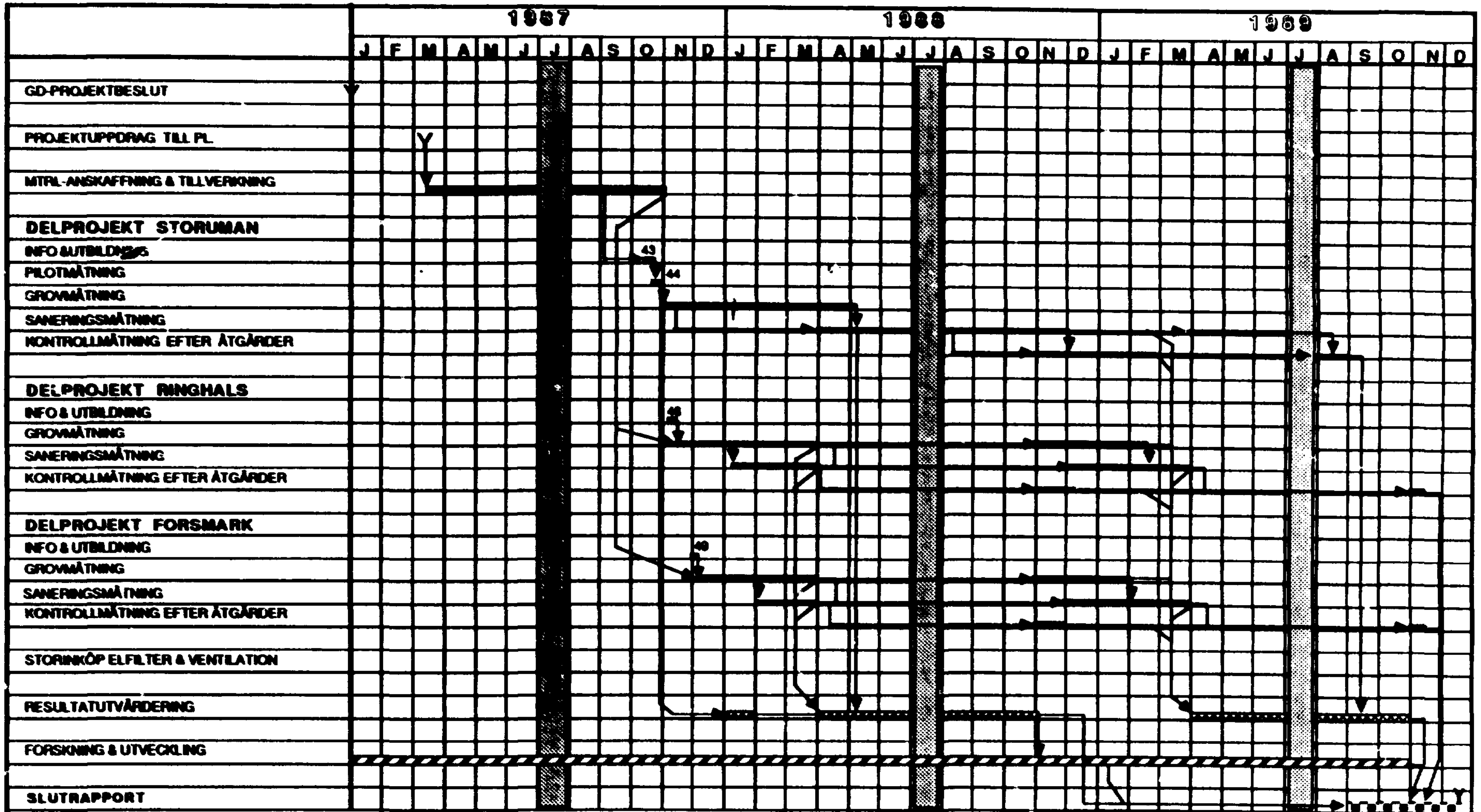
En åtgärdskatalog skall tas fram under 1988. Samarbete med ventilationsföretag utökas för att väcka deras intresse för systemlösningar och för att förmå dem att lämna garantier. Åtgärdspaket för självmontage (IKEA-modell) skall tas fram.

Olika alternativ till bidrag och lån för genomförande av saneringsåtgärder skall studeras.

Vidareutveckling av radonfilterutrustning

Typgodkännande av ELFI:S och ELIXAIR:s filter slutförs. Test av några mekaniska filter genomförs. Enkla givare av elektrostatiska fält testas i praktiken. Möjligheten att enkelt kunna mäta effektiviteten hos elfilter i hemmiljö undersöks.

Möjligheten att sänka stråldosen till under 30% studeras genom optimering av elfilter och elektrostatiska fälten i rummet.



Avv	Not	Ändring	Dat	Inl	Godk	Tillhörande ritningar etc.	Ritn nr
	A	OMRITAD	871002	UR			

Avd. BEA2

PROJEKT RADON
FUD-PROJEKT NR 98233
PKK-PROJEKT NR 60713
HUVUDTIDPLAN

Ritad UR 87-04-02
Granskad
Konstr
Godkänd
Skala NTS
Grupp
Blad
Fort bl
Ritn nr 3-BEA2-1299 A

Utgåva 5

1988-01-22

P R O J E K T   R A D O N

Adress- och telefonlista

Bilaga 2

1. RADONPROJEKTETS LEDNING

Namn		Telefon	Adress

1.1 LEDNINGSGRUPPEN

Namn		Telefon	Adress
V Mets	UP	08-739 5453 tj	Vattenfall UP Attn: V Mets 162 87 VÄLLINGBY
K Egner	RT	0340-67150 tj	Vattenfall Ringhalsverket Attn: K Egner RT 430 22 VÅRÖBACKA
L Wahlström	FR	0173-81000 växel 81005 direkt	Vattenfall Forsmarksverket Attn: L Wahlström FR 742 00 ÖSTHAMMAR
L Semrén	MN	0951-11094 hem 0951-42050 tj	Leif Semrén Hammarvägen 20 923 00 STORUMAN
T Isaksson	MR	08-739 6255	Vattenfall MR Attn: T Isaksson 162 87 VÄLLINGBY
S Ekholm	PK	Se projektledare	

1. RADONPROJEKTETS LEDNING

Namn		Telefon	Adress
1.2 PROJEKTLEDARE			
Sam Ekholm	PKK	08-739 7091	Vattenfall PKK Attn: Sam Ekholm 162 87 VÄLLINGBY
Ulf Rossby	BEA2	08-739 5387	Vattenfall BEA2 Attn: Ulf Rossby 162 87 VÄLLINGBY
1.3 DELPROJEKTLEDARE			
L Wahlström	PF	0173-81005	Vattenfall Forskmarksverket Attn: L Wahlström FR 742 00 ÖSTHAMMAR
S Eliasson	RTSD	0340-67285	Vattenfall Ringhalsverket Attn: S Eliasson 430 22 VÄRÖBACKA
L Semrén	NK6D	0951-11094 hem	Leif Semrén Hammarvägen 20 923 00 STORUMAN

2. FORSKNING

	Namn	Telefon	Adress
2.1	DTH		
	Prof Jonassen	00945-2-882488	Danmarks Tekniska Högskola Attn: Prof Jonassen DK-2800 LUNGBY Danmark
2.2	TTH		
	Prof Graeffe	358-31-16211	Tampereen Teknillinen Korkeakoulu Attn: Prof Graeffe Pl 527 SF-33101 TAMPERE Finland
2.3	LUND		
	Doc Samuelsson	046-101000	Lunds Lasarett Radiofysiska Inst Attn: D Samuelsson 221 85 LUND
2.4	STUDSVIK		
	H Tovedahl	0155-21000	Studsvik Energiteknik AB Attn: H Tovedahl 611 82 NYKÖPING
	Biblioteket	0155-21000	Studsvik Energiteknik AB Biblioteket 611 82 NYKÖPING

3. INDUSTRI

Namn		Telefon	Adress
3.1 FLÄKT AB			
O Strindehag		036-193000	Fläkt AB Attn: O Strindehag Åsenvägen 7 551 84 JÖNKÖPING
H Gerdin S Borgström	Dir Utv chef	090-23010	Fläkt Bostadsventilation AB Attn: S Borgström Box 56 913 00 HOLMSUND
3.2 LGH-KANALFLÄKT			
Per-Anders Näslund	Försälj	0222-11430	LGH Kanalfläkt AB Attn: Per-Anders Näslund Industrivägen 3 779 00 SKINNSKATTEBERG
3.3 ELIXAIR			
Hans Karlsson Lea Vuori	Dir Försälj	08-145445	Elixair c/o UPO Attn: Lea Vuori Kungsgatan 48 111 35 STOCKHOLM
Kivisto	Utv. chef	009358-55-368900	Elixair OY Attn: Kivisto Työmienkatu 2 SF-50100 S:T MICKEL Finland

3. INDUSTRI

Namn		Telefon	Adress
3.4 ELFI			
Jan Olof Wallin Susanne Löwhagen	Dir Försälj	0510-60245	Elfi Attn: Jan Olof Wallin Box 24 531 21 LIDKÖPING
Månsson	f.d utv.chef	036-16 44 40	Månsson Södra parkgatan 3 561 42 HUSQVARNA
3.5 ZIEHL			
Ingrid Sannefors	Försälj	08-795 9100	Svenska Ziehl AB Attn: Ingrid Sannefors Äggelundavägen 2 175 62 JÄRFÄLLA
3.6 STAEFA Control System OEM			
Benkt Ljungberg		031-550005	STAEFA Control System OEM Attn: Benkt Ljungberg Tuvevägen (Gårda Johan center) 417 05 GÖTEBORG
3.7 ALNOR			
Lennart Svansson		0155-680 50 Telefax: 63110	ALNOR INSTRUMENT AB Attn: Lennart Svansson 611 82 NYKÖPING

4. VATTENFALL INTERNT

Namn		Telefon	Adress
4.1 RÅCKSTA			
C-E Nyqvist	Gd	08-739 5000	Vattenfall Attn: Gd C-E Nyquist 162 87 VÄLLINGBY
G Apelqvist	UK	08-739 5339	Vattenfall Attn: G Apelqvist 162 87 VÄLLINGBY
H Jonsson	I	08-739 5092	Vattenfall Attn: H Jonsson 162 87 VÄLLINGBY
I Christoferson	IV	08-739 5098	Vattenfall Attn: I Christoferson 162 87 VÄLLINGBY
S Sandklef	cPK	08-739 7273	Vattenfall Attn: cPK Stig Sandklef 162 87 VÄLLINGBY

4. VATTENFALL INTERNT

Namn		Telefon	Adress
4.2 FORSMARK			
A. Lindfors	cPF	0173-81001	Vattenfall Forsmarksverket Attn: cPF A. Lindfors 742 00 ÖSTHAMMAR
4.3 RINGHALS			
H Johansson	cPR	0340-67000	Vattenfall Ringhalsverket Attn: cPR H. Johansson 430 22 VÄRÖBACKA

4. VATTENFALL INTERNT

Namn		Telefon	Adress
4.3 MELLERSTA NORRLAND			
Huvudkontor Friström	cMN	060-198000	Vattenfall Mellersta Norrland Attn: Friström 851 74 SUNDSVALL
Umeådistriktet Backlund	cNP	090-118850	Vattenfall Mellersta Norrland Umeådistriktet Attn: Backlund Box 63 901 03 UMEÅ
Driftkontor Umeå	cNKD3	090-118850	Vattenfall Mellersta Norrland Driftkontoret Box 63 901 03 UMEÅ
Driftkontor Storuman Harry Söder	cNK6d		Vattenfall Mellersta Norrland Driftkontoret Attn: H Söder 923 00 STORUMAN

5. MYNDIGHETER

Namn	Telefon	Adress
5.1 STRÅLSKYDDSINSTITUTET		
G Svedjemark	08-729 7100	Statens Strålskyddsinstitut Attn: G Svedjemark Box 60204 104 01 STOCKHOLM
R Falk	08-729 7100	Statens Strålskyddsinstitut Attn: R Falk Box 60204 104 01 STOCKHOLM
5.2 PLANVERKET		
W Tell	08-737 5500	Statens Planverk Attn: W Tell Box 12513 102 29 STOCKHOLM
5.3 SOCIALSTYRELSEN		
A Mäkitalo	08-783 3000	Socialstyrelsen Attn: A Mäkitalo 106 30 STOCKHOLM

6. KOMMUNER

Namn	Telefon	Adress
6.1 DELPROJEKT FORSMARK		
Östhammars Kommun Katarina Österholm	0173-109 00	Östhammars Kommun Miljö och hälsoskyddsnämnden Attn: Katarina Österholm Box 66 742 00 ÖSTHAMMAR
Östhammars Kommun Birger Norén	0173-109 00	Östhammars Kommun Byggnadsnämnden Attn: Birger Norén Box 66 742 00 ÖSTHAMMAR
Tierps Kommun Anders Oskarsson	0293-117 60	Tierps Kommun Miljö och hälsoskyddsnämnden Attn: Anders Oskarsson Box 6000 815 00 TIERP

6. KOMMUNER

Namn		Telefon	Adress
6.2 DELPROJEKT STORUMAN			
Storumans Kommun K Olin		0951-11320	Storumans Kommun Miljö och hälsoskyddsnämnden Attn: K Olin Blå vägen 242 923 00 STORUMAN
Å Gavelin	Ordf	0951-11320	Storumans Kommun Byggnadsnämnden Attn: Å Gavelin Blå vägen 242 923 00 STORUMAN
6.3 DELPROJEKT RINGHALS			
Varbergs Kommun Jörgen Bengtsson Torbjörn Sundsten		0340-887 96 0340-887 96 -882 70	Varbergs Kommun Miljö och hälsoskyddskontoret Attn: Jörgen Bengtsson Box 504 432 01 VARBERG
Marks Kommun Lennart Axelsson Ove Linder		 0320-172 79 172 76	Marks Kommun Miljö och hälsoskyddskontoret Attn: Lennart Axelsson Box 500 511 01 KINNA

6. KOMMUNER

Namn	Telefon	Adress
6.3 forts.		
Kungsbacka Kommun Per Eckberg	0300-340 00 0300-341 36 (9-10) 031-14 53 72 hem	Kungsbacka Kommun Miljö och nälsoskyddskontoret Attn: Per Eckberg 434 81 KUNGSBACKA
6.4 SKARA		
Skara Kommun Kjellberg	0511-16300	Skara Kommun Miljö och hälsoskyddsnämnden Attn: Kjellberg Box 210 532 00 SKARA
Svenska Kommunförbundet Attn: Melander	08-772 4100	Svenska Kommunförbundet Attn: Melander Hornsgatan 15 116 47 STOCKHOLM

7. ÖVRIGA

Namn	Telefon	Adress
6.4 forts.		
Utbildningsproduktion AB L Svensson	040-291050	Utbildningsproduktion AB Attn: L Svensson Box 16045 200 25 MALMÖ
ES-Konsult Erik Söderman AB A Sjöstedt	08-372750	ES-Konsult Erik Söderman AB Attn: A Sjöstedt Arvid Mörnes väg 22 161 59 BROMMA
Fem Konsulter inom Reklam & Kommunikation AB H Larsson	08-240705	Fem Konsulter inom Reklam & Kommunikation AB Attn: H Larsson Barnhusgatan 4 111 23 STOCKHOLM
Folksam Hans Gustavsson	08-743 68 41	Folksam Attn: H Gustavsson Box 20500 Bohusgatan 14 104 60 STOCKHOLM

Bil. 3

PROGRESS REPORT NO XIII

STATENS VATTENFALLSVERK
VATTENFALL

NIELS JONASSEN and BENT JENSEN

RADON DAUGHTER LEVELS IN INDOOR AIR
EFFECTS OF FILTRATION AND CIRCULATION

LABORATORY OF APPLIED PHYSICS I
TECHNICAL UNIVERSITY OF DENMARK
2800 LYNGBY, DENMARK

NOVEMBER 1987

NIELS JONASSEN and BENT JENSEN

R A D O N   D A U G H T E R   L E V E L S   I N   I N D O O R   A I R

EFFECTS OF FILTRATION AND CIRCULATION

PROGRESS REPORT XIII

NOVEMBER 1987

LABORATORY OF APPLIED PHYSICS I
TECHNICAL UNIVERSITY OF DENMARK
BUILDING 307, 2800 LYNGBY
DENMARK

INTRODUCTION

In PROGRESS REPORT XII a theory was developed for the field modifying effect of space charges with special respect to the plateout of airborne radon daughters.

The first part of the present report consists of a paper to be presented at the IVth International Conference on Natural Radiation Environment in Lissabon, December 7 - 11, 1987.
This paper builds upon the theoretical results of PR XII and describes after further development an experimental investigation of field induced plateout of radon daughters.

MODIFICATION OF ELECTRIC FIELDS BY SPACE CHARGES

EFFECTS ON AIRBORNE RADON DAUGHTERS

NIELS JONASSEN and BENT JENSEN

ABSTRACT
The mean field strength in a electric field between two electrodes is given by the voltage difference divided by the electrode spacing. The variation of the field between the electrodes, however, depends strongly upon the electrode shape and upon whether or not the inter-electrode space contains an excess space charge.
The paper describes an investigation where an electic field is established in a laboratory room, with radon and radon daughter activities about 1000-1500 Bq/m^3, by placing four corona emitters below the ceiling and operating them at voltages from 0 to 30 kV. It is demonstrated that the field induced plateout of the radon daughters increases strongly when corona ionizaton starts, and that it is possible to lower the potential alpha energy concentration with about 86 % and the radiological bronchial dose with about 50 % of their original values. The potential alpha energy of and the dose from unattached radon daughters are almost unaffected by ionization and electric fields.
Positive ionization is considerably more effective than negative ionization.

INTRODUCTION

It has been shown[1,2] that airborne radon daughters to some degree are electrically charged or at least affectable by electric fields. A suitable electric field in a room will thus remove radon daughters from the air and consequently cause a reduction in the potential alpha energy concentration. It has also been indicated,[3,4,5] that supplementing ionization might have a positive effect on the removal efficiency of the field.

THEORY

We will consider two ways in which to establish an electric field in a given room and evaluate the relative efficiencies of the fields to remove charged radon daughters from the atmosphere.

For the sake of simplicity we assume the room to be spherical with a radius R and the potential of the walls to be zero.

Let us consider the i^{th} radon daughter of which a fraction c_i is charged with a certain polarity and with a mean mobility k_i. If the concentration of the element at the wall is $N_i(R)$ and the field strength E(R) (of such a direction as to move the charged particles towards the wall), the total number of atoms of the element considered, removed per unit time from the room by the field, is

$$4\pi R^2 k_i c_i N_i(R) E(R) \qquad (1)$$

For a given production rate, i.e. a given airborne concentration of the $(i-1)^{th}$ daughter product, the concentration of the i^{th} daughter throughout the room will to some degree depend upon the variation of the field strength with the distance from the center, but it seems likely that the overriding determining removal parameter is the electrical field strength at the boundary of the room.

The simplest way in which to establish an electric field in the room considered is to place a (spherical) electrode with the radius r at the center of the room.

If the voltage of the central electrode is V the mean field strength E_m is

$$E_m = \frac{V}{R-r} \qquad (2)$$

a) Spherical capacitor-system.

If no excess charge is created in the atmosphere the system functions as a spherical capacitor and the actual field strength at a distance x from the center is

$$E_c(x) = \frac{V}{x^2(1/r-1/R)} \qquad (3)$$

Whether or not this condition is fulfilled is a question of the shape of the electrode and the value of V.

b) Corona/space charge system.

If such a combination of electrode voltage V and radius of curvature r is chosen, that a corona current flows from the electrode towards the boundary of the room a space charge is created which will modify the variation of field strength with the distance from the electrode. It can be shown[6] that in this case

$$E_i(x) = \frac{V}{2(\sqrt{R}-\sqrt{r})\, x} \qquad (4)$$

If we assume that the radius r of the central electrode in the spherical capacitor system is the same as the radius of the corona volume in the corona/space charge system, the mean field strength, from r to R, is, at a given electrode voltage V, in both cases given by equation (2).
Since in most cases R>>r we find at the boundary of the system, i.e. for $x = R$, for the ratio between the field strength in the case of ionization (and space charge), $E_i(R)$, and the field strength in the spherical capacitor system, $E_c(R)$,

$$\frac{E_i(R)}{E_c(R)} = \frac{R}{2r} \qquad (5)$$

For practical values of R and r this ratio may be in the order of 100 to 1000, indicating that the depletion power of the corona-space charge system is much higher than that of the spherical capacitor system, independent of the corona current.
The total amount of activity removed, however, also depends upon the concentration of the element considered at the boundary of the room.
The variation of the concentration with the distance from the center of the room can be derived in the following manner.
The production rate, i.e. the number of atoms formed per unit volume per unit time, of the i^{th} daughter product is $\lambda_{i-1}N_{i-1}$, where λ_{i-1} and N_{i-1} are the decay constant and the concentration of the $(i-1)^{th}$ daughter, i.e. λ_o and N_o refer to radon itself. The concentration $N_i(x)$ at a distance x from the center is then determined by

$$4\pi x^2 dx \cdot dN_i(x)/dt = 4\pi x^2 dx(\lambda_{i-1}N_{i-1}(x)-\lambda_i' N_i(x)) + E(x)N_i(x)k_i c_i 4\pi(x^2-(x+dx)^2) \qquad (6)$$

where λ_i' is the effective removal rate for the i^{th} daughter including all removal processes (also radioactive decay) except field induced removal.
Neglecting second order terms the equilibrium airborne activity concentration $A_{ia}(x)$ is

$$A_{ia}(x) = \lambda_i N_i(x) = \lambda_{i-1}N_{i-1}(x)\frac{\lambda_i}{\lambda_i'+\lambda_{ie}} \qquad (7)$$

where

$$\lambda_{ie} = 2k_i c_i E(x)/x \qquad (8)$$

is the field induced removal rate constant.
If no field is applied the equilibrium activity concentration is

$$A_{ia} = \lambda_i N_{i,o} = \lambda_{i-1}N_{i-1}\frac{\lambda_i}{\lambda_i'} = A_{i-1}\frac{\lambda_i}{\lambda_i'} \qquad (9)$$

Eqs. (7) and (9) thus indicate that the effect of the applied field is to lower the activity with the factor

$$\frac{\lambda_i N_i(x)}{\lambda_i N_{io}} = \frac{\lambda_i'}{\lambda_i'+\lambda_{ie}} \qquad (10)$$

The field induced plateout rate, i.e. the amount of activity removed per unit time per unit volume at the boundary of the room, $A_{ip}(R)$, is

$$A_{ip}(R) = \lambda_{ie}N_i(R) = \lambda_{i-1}N_{i-1}(R)\frac{\lambda_{ie}}{\lambda'_i+\lambda_{ie}} = A_{i-1,a}(R)\frac{\lambda_{ie}}{\lambda_i'+\lambda_{ie}} = A_{ia}(R)\frac{\lambda_{ie}}{\lambda_i} \qquad (11)$$

The efficiency of the removal process can now be characterized by the two coefficients:
the normalized field plateout efficiency, p_a, defined as the fraction of the activity produced which is plating out

$$p_{ia} = \frac{A_{ip}(R)}{A_{i-1,a}(R)} = \frac{\lambda_{ie}}{\lambda_i+\lambda_{ie}} \qquad (12)$$

and the relative field plateout efficiency, p_r, defined as the ratio between the plated out activity and the activity remaining airborne

$$p_{ir} = \frac{A_{ip}(R)}{A_{ia}(R)} = \frac{\lambda_{ie}}{\lambda_i} \qquad (13)$$

An examination of p_a and p_r may give useful information about the plateout process and the electrical properties of the radon daughters.
According to equation (8) λ_{ie} will increase proportionally with the emitter voltage, V, assuming that the product $k_i c_i$ stays constant. This can be checked by determining p_r as a function of V. Similarly the variation of p_a with V will show the dependence of the electrical plateout efficiency with the emitter voltage.
Although the theory has been developed for a spherical room, it is expected that the general trends can also be found in experimental results obtained in a room of more conventional shape.
The direct effect of the plateout on the level of airborne radioactivity can be described by measuring or calculating, as a function of the emitter voltage, a series of parameters, characterizing the radioactive state of the air. These parameters are:

the individual daughter relative activities $a_i = A_{ia}/A_o$ (relative to radon),

the equilibrium factor (or normalized potential alpha energy concentration)

$$F = 0.105a_1 + 0.516a_2 + 0.380a_3 \quad (7) \qquad (14)$$

the radiological dose to a certain part of the respiratory tract (normalized to a fixed radon concentration, for instance 1 Bq/m^3). The calculation of the dose from the relative daughter concentrations depends upon what dose model and population group are considered.

EXPERIMENTAL RESULTS

A series of plateout measurements were performed in a 150 m^3 room with a radon concentration of about 1000-1500 Bq/m^3. About 0.5 m below the ceiling four corona emitters, spaced approximately 1.5 m apart, were mounted, Figure 1. The emitters are through a high ohmic resistor connected to a high voltage supply, and the voltage drop across the resistor is measured, by a floating static voltmeter, giving the corona current.

Preliminary measurements indicated that the reduction in the daughter activities caused by the combined effect of the ionization and the field, was higher for positive corona than for negative, and the measurements to be reported here were therefore performed with positive corona exclusively.

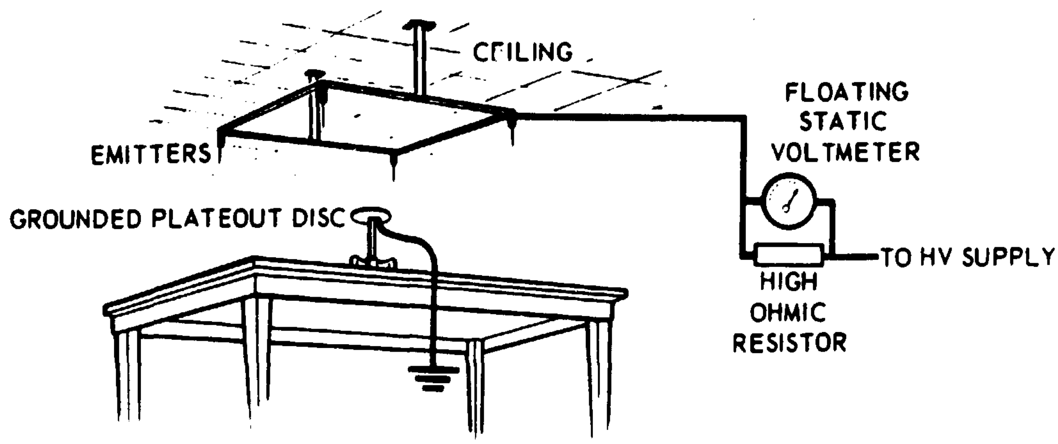


Figure 1. Experimental set-up for measuring space charge/field induced plateout of radon daughters.

The following parameters were measured: radon concentration, by grap sampling and counting in scintillations cells, individual radon daughter concentrations and unattached fractions, by alpha spectroscopy of membrane filters and wire screens, aerosol concentrations and AMD, by condensation nucleus counter and diffusion boxes, and corona current as described above. A rough estimate indicated that even at the highest emitter voltages the average plateout rate would only be about 200-300 atoms$\cdot m^{-2}\cdot s^{-1}$ which is too low to be detected with a reasonable accuracy when collected on a disk of approximately 10^{-3} m^2. In order to increase locally the plateout rate over a small area grounded metal collector disks were placed about 0.40 m above the table directly beneath the emitters, see Figure 1. The field strength at the disk is distorted and much stronger than at the table top. When the emitter voltage is changed the field at the disk is changed proportionally, but the shape of the field is constant, as long as the position of the disk is maintained.

During the measurements an aerosol concentration of about $5\cdot 10^{10}$ m^{-3} with an AMD of about 0.1 µm was maintained.

The activity collected on the disks was analyzed in the same manner as the activity collected on filters and wire screens.
Let the activity of the i^{th} daughter collected on the disk be A_{id}. For each point in the room we then have

$$A_{id} = d_i A_{ip}(R) \qquad (15)$$

where the constant d_i will vary from point to point in the room because of the variation of the field strength.
From equations (12), (13) and (15) we find the disk-related constants p_{ida} and p_{idr}

$$p_{ida} = \frac{A_{id}}{A_{i-1,a}(R)} = d_i\frac{A_{ip}(R)}{A_{i-1,a}(R)} = d_i\frac{\lambda_{ie}}{\lambda_i+\lambda_{ie}} = d_i p_{ia} \qquad (16)$$

$$p_{idr} = \frac{A_{id}}{A_{ia}(R)} = d_i\frac{A_{ip}(R)}{A_{ia}(R)} = d_i\frac{\lambda_{ie}}{\lambda_i} = d_i p_{ir} \qquad (17)$$

In Figure 2 are shown p_{1da} and p_{1dr} for ^{218}Po and in Figure 3 the corresponding coefficients p_{2da} and p_{2dr} for ^{214}Pb. The unit used is (atoms/s)/(Bq/m^3). The plateout activities of ^{214}Bi were too low to allow an accurate analysis.
The relative concentrations of ^{218}Po, ^{214}Pb, and ^{214}Bi are shown in Figure 4 as a function of the emitter voltage V.
From the relative daughter concentrations the equilibrium factor F_t for the total daughter population as well as the equilibrium factor F_u for the unattached daughters are calculated and plotted in Figure 5. Shown in Figure 5 are also the normalized mean bronchial doses from the total daughter population and from the unattached daughters, calculated in two ways. The lower curves are calculated from the individual daughter relative activities and their unattached fractions, using the James-Birchall-[9], the Harley-Pasternack-[9,10], and the Jacobi-Eisfeld-models[11] and averaging over six age and activity groups.
The formulas and conversion factors used were developed in 1984-1985. Since then a reevaluation of the relation between exposure and resulting dose has

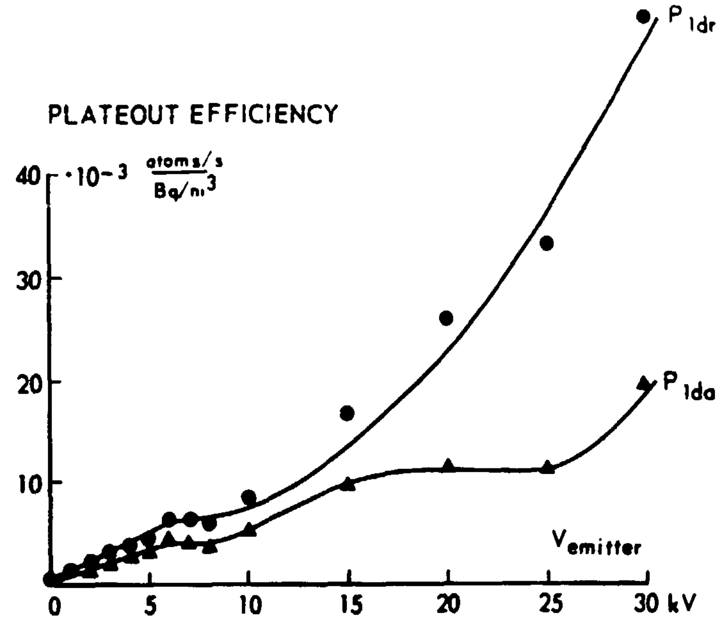


Figure 2. Disk-related field plateout efficiencies for ^{218}Po as a function of the emitter voltage.

P_{1da}: normalized disk plateout efficiency, P_{1dr}: relative disk plateout efficiency.

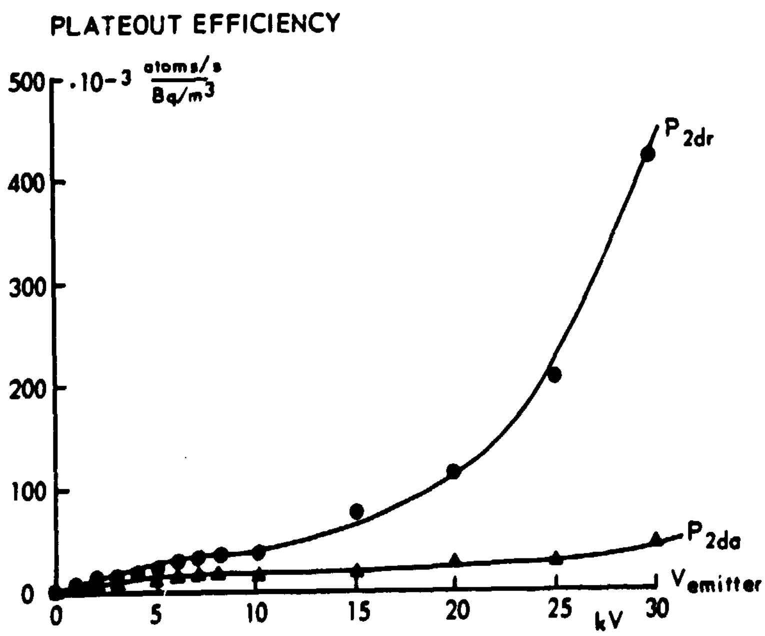


Figure 3. Disk-related field plateout efficiencies for ^{214}Pb as a function of the emitter voltage.

P_{2da}: normalized disk plateout efficiency, P_{2dr}: relative disk plateout efficiency.

been made, linking the dose to the potential alpha energy concentration (unattached and attached) rather than to the individual daughter activities, and also resulting in higher conversion factors.[12] The result of this is shown in the upper curves where the doses are calculated from the equilibrium factors (normalized potential alpha energy concentrations) F_t and F_u for the total daughter population and the unattached daughters respectively. These doses correspond most closely to those calculated from the individual daughter relative activities by the use of the James-Birchall- and Harley-Pasternack-models for adults with high breathing rate.

DISCUSSION OF THE RESULTS

It appears from Figures 2 and 3 that the relative field plateout efficiency, p_{dr}, for both daughter products increases almost proportionally with V for voltages up to about 5 kV, i.e. in this region kc is constant. In the region 5 - 10 kV p_{1dr} and p_{2dr} change very little with V, indicating that kc decreases in this region. From about 10 kV both constants increase strongly with V. This is also the region where the emitters go into corona,[6] and although this in itself, according to equation (5), will cause an increase in the field strength and hence in λ_e, if kc stays constant, the increase in p_{1dr} and p_{2dr} with the emitter voltage is so pronounced that it is believed to be related to an extra charging of the radon daughters by the corona current.

The variation in p_{da} with the emitter voltage is also reflected in the curves showing p_{1dr} and p_{2dr} as a function of V. After the initial increase with increasing λ_{1e} p_{dr} flattens out, indicating an almost constant value of λ_{1e}, and at high emitter voltages, about 25 - 30 kV, p_{da} will again increase but not as strongly as p_{dr}, which is also what should be expected from equations (16) and (17).

Figures 2 and 3 predict that the effect of the field induced plateout on the airborne activities of the radon daughters should be more pronounced in the case of ^{214}Pb than with ^{218}Po. This is in good accordance with Figure 4, which shows, that while the relative activity of ^{214}Pb, for an increase in emitter voltage from 0 to 30 kV, decreases with about 90 %, the corresponding decrease in the relative activity of ^{218}Po is less than 50 %. It also appears from Figure 4 that the relative activity of ^{214}Bi follows that of ^{214}Pb very closely, indicating that field induced plateout of ^{214}Bi is negligible.

The results plotted in Figure 5 show that the equilibrium factor for the unattached daughters, F_u, is almost constant about 0.03, independent of the emitter voltage, while the total equilibrium factor, F_t, decreases from about 0.42 at an emitter voltage of 0 to approximately 0.07 at 30 kV.

These results are also reflected in the variation of the doses with the emitter voltage, with the dose from the unattached daughters being almost constant, while the total dose at 30 kV has decreased with about half of its value at an emitter voltage of 0. At 30 kV 87 % of the total dose is due to unattached daughters.

The scatter in the points is probably due to unavoidable variations in the experimental conditions, especially the aerosol concentration, from one day to another, which may have a rather pronounced effect on the unattached daughter activity and thus on the unattached potential alpha energy concentration.

The doses calculated from the potential alpha energy concentrations are about twice the doses calculated from individual daughter activities, which is what could be expected from the difference in the methods already mentioned.

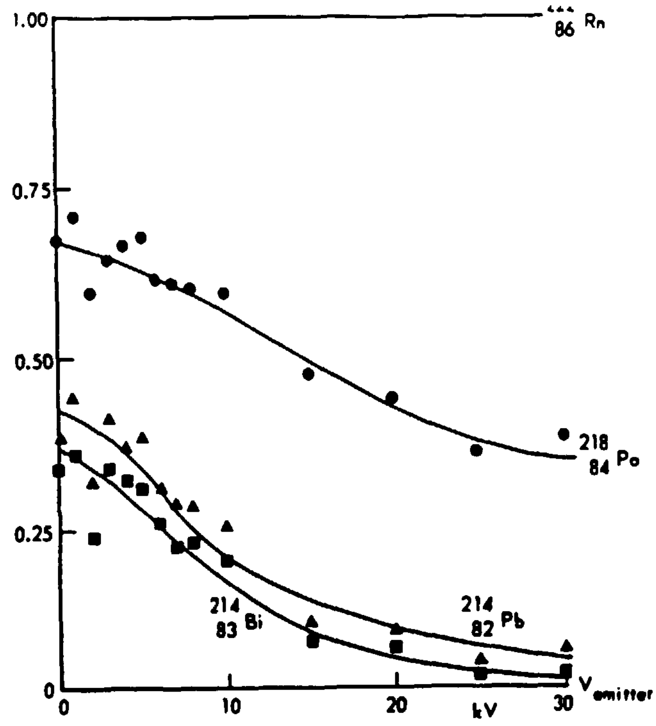


Figure 4. Relative concentrations of ^{218}Po, ^{214}Pb, and ^{214}Bi as a function of the emitter voltage.

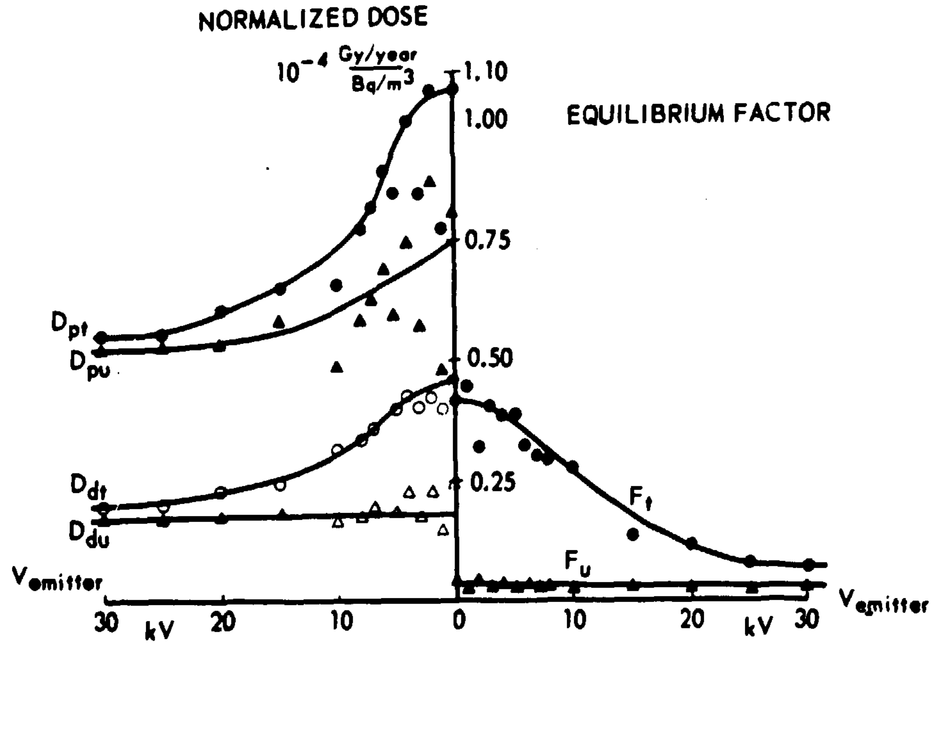


Figure 5. Equilibrium factor and normalized mean bronchial dose as a function of the emitter voltage.

F_t: equilibrium factor of attached + unattached radon daughters.
F_u: equilibrium factor of unattached radon daughters
D_{pt}: dose calculated from normalized total potential alpha energy concentration
D_{pu}: dose calculated from normalized unattached potential alpha energy concentration
D_{dt}: dose calculated from total individual radon daughter concentrations
D_{du}: dose calculated from individual unattached radon daughter concentrations.

CONCLUSION

It has been demonstrated that by a combination of ionization and electric fields it is possible to cause airborne radon daughters to plateout on the surfaces of the room, in which the field is established.

The plateout rate is higher for ^{214}Pb than for ^{218}Po and almost negligible for ^{214}Bi.

It appears that only the activity of the attached daughters is affected to any significant degree by the electric field. This may not necessarily mean that unattached daughters are not charged and plating out, but rather that the plateout process itself, by removing aerosol particles from the air, causes more daughter products to stay unattached and thus compensates for the unattached plateout.

By the experiments described above the total potential alpha energy concentration was lowered with about 83 % and the radiological dose with about 50 % of their original values.

It should be stressed that the experiments are made under laboratory conditions, but it can be mentioned that preliminary work with small book sized ionizers in ordinary office and other work rooms indicates results very similar to those reported here.

ACKNOWLEDGMENT

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FURTHER COMMENTS ON THE RESULTS PRESENTED IN THE PREVIOUS PAPER

Referring to Figs. 2 and 3 on page 7 it appears that the relative plateout ability is considerably higher for ^{214}Pb than for ^{218}Po suggesting that a higher fraction is (positively) charged.
These two features are also reflected in the curves shown in Figure 4. It is possible to remove almost all of ^{214}Pb (and ^{214}Bi) while even at the highest emitter voltages the relative concentration of ^{218}Po is still about 0.40.

From a remedial point of view, however, the results shown in Figure 5 are probably more interesting.
Although the general trends already have been given in the conclusion of the paper itself, they should also be highlighted here:

By raising the emitter voltage to +30 kV the total potential alpha energy concentration, or EEC, or in daily language the radon daughter content, is reduced with about 84 % of the untreated value.
But it is noteworthy that during this process the contribution from the unattached daughters is almost unchanged, reflected in an unattached daughter equilibrium factor of 0.03.

When the corresponding radiological doses are considered, the same trend prevails.
The total dose is reduced to about half of its original value, but the dose from the almost unchanged concentration of unattached daughters undergoes only minor changes, especially when the doses are calculated on basis of individual daughter concentrations.

As mentioned in the paper the doses calculated on basis of the potential alpha energy concentration are considerably higher than those arrived at from individual daughter concentrations, but as Figure 5 shows the effect of the space charge/ions and fields is about the same independently of the way of calculating the doses.

CONCLUSION

It thus appears that space charge/ions and electric fields, at least on an integrated level, primarily affects the attached dauughters and leaves both the potential alpha energy concentration of and the dose from the uattached daughters unchanged.

In order to see if this is also true, when filtration is employed for the removal of radon daughters, previous results of filtration employing the ELIXAIR 1100 electrofilter have been recalculated using the principles discussed above.

The results are shown in Figure 6. Also in this case the effect of the treatment (filtration) is much more pronounced as far as the attached daughters are concerned than with the unattached ones.

The concentration of unattached daughters (as reflected in the unattached equilibrium factor) does, however, show a slight decrease with increasing filtration rate, resulting in a stronger decrease in the doses, both calculated from individual daughter concentrations and from the potential alpha energy concentration.

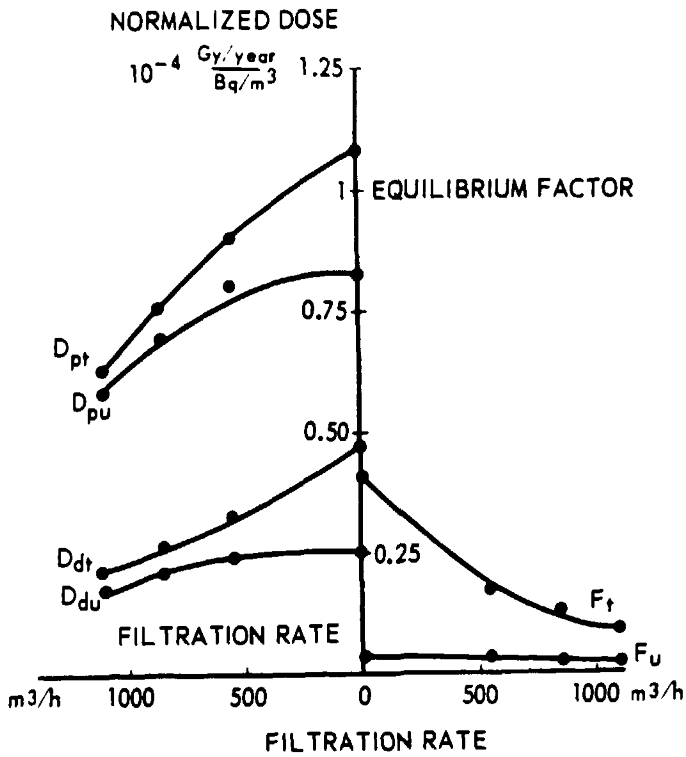

Figure 6. Equilibrium factor and normalized mean bronchial dose as a function of the filtration rate.

F_t: equilibrium factor of attached + unattached radon daughters.
F_u: equilibrium factor of unattached radon daughters
D_{pt}: dose calculated from normalized total potential alpha energy concentration
D_{pu}: dose calculated from normalized unattached potential alpha energy concentration
D_{dt}: dose calculated from total individual radon daughter concentrations
D_{du}: dose calculated from individual unattached radon daughter concentrations.

The resemblance between the results with space charge/ions and fields on one hand and filtration on the other hand is striking. With both techniques the potential alpha energy may be reduced to about 10 - 20 % and the doses to about 50 % and in both cases is the effect primarily due to removal of attached radon daughters.

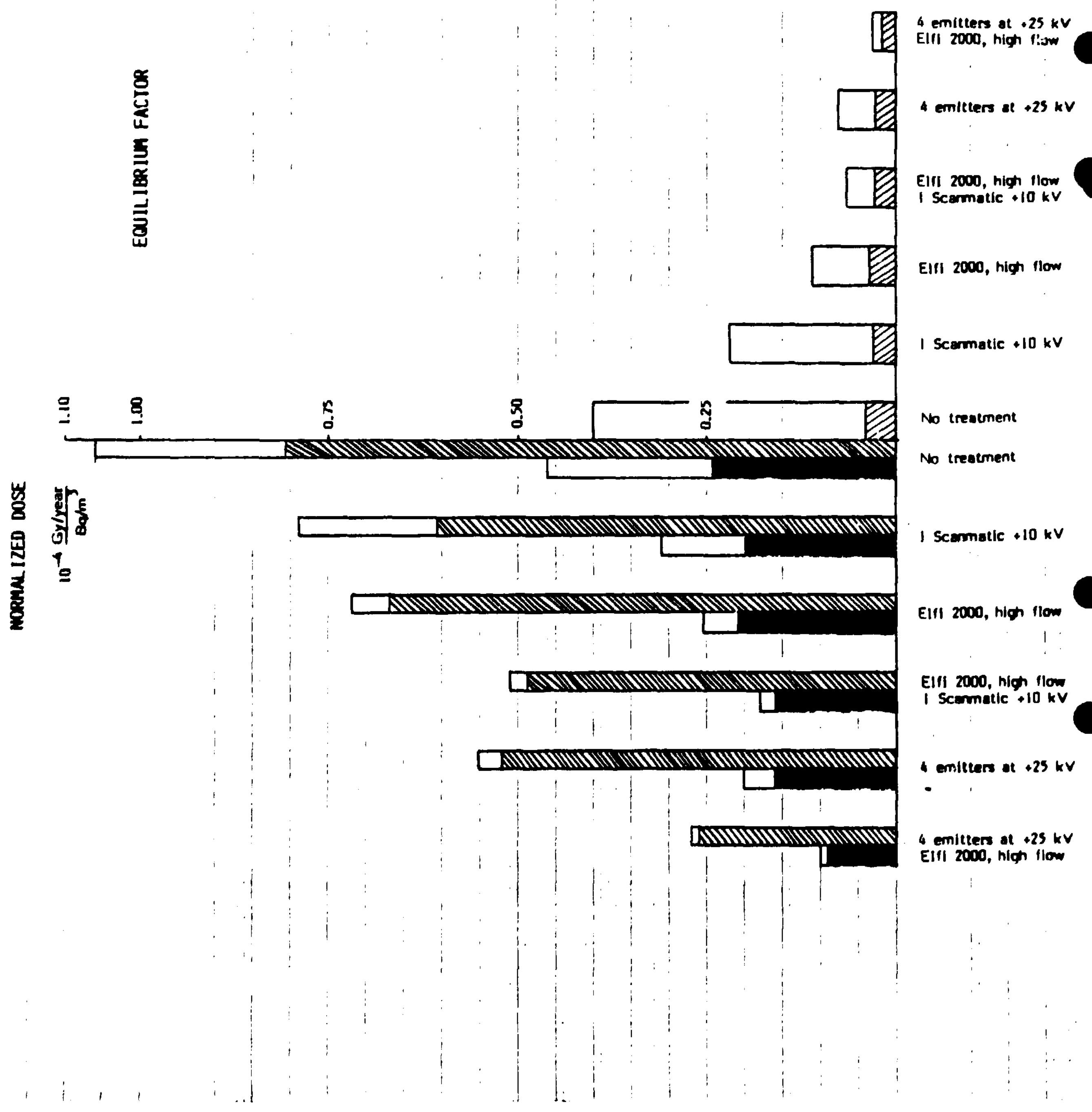

Figure 7. Equilibrium factor and normalized mean bronchial dose for various combinations of filtration and/or ionization of the air.

In Figure 7 is finally shown the results of a series of combinations of filters and ionizers, used separately and jointly.
In the equilibrium factor region the open bars indicate the equilibrium factor of attached + unattached radon daughters while the hatched bars refer to the unattached daughters alone.

In the dose region the hatched bars refer to the dose calculated from normalized unattached potential alpha energy concentration while the solid bars give the dose calculated from individual unattached radon daughter concentrations. The open bars correspond to the doses calculated from either normalized total potential alpha energy concentration or total individual radon daughter concentrations.

The smallest effect is found with the use of a small Scanmatic Ionizer (at +10 kV) where the equilibrium factor is reduced with about 45 % and the doses with about 30 % of the untreated values, while with the combined use of ELFI 2000 and 4 emitters at +25 kV the equilibrium factor is reduced with about 92 % and the doses with about 75 % of the untreated values.

The latter result is beleived to be about the maximum possible reduction, and we are at the moment attempting to reach this range of reductions with smaller and more handy devices.

Since the room in which the experiments have been carried out is rather large compared to most living rooms we have also started measurements in smaller rooms in order to find the relation between the efficiency of an ionizer and the room size.

POSTSCRIPT

We would like to suggest:

1) that we check and calibrate the radon measurering devices used by Vattenfall.

2) that Vattenfall arranges a selection of mechanical filters, comparable in capacity to the electro filters already examined, to be sent to Denmark for examination.

We would also like to hear the result of the plan of having Elixair and Elfi to manufacture a couple of filters with different electrical properties.

LABORATORY OF APPLIED PHYSICS I
November 13, 1987

NIELS JONASSEN and BENT JENSEN

Projekt Radon

REV. 1

		1987 P 13		1988	1989
		Kalkyl	Utfall	Kalkyl	Kalkyl
PKK	Löner	146	174,0	150	184
	Resor	50	51,0	40	60
	Upphandlingar	1030	947,7	500	110
	Forskning DTH	300	278,0	280	320
	Forskning TTH	80	0,0	120	120
	Konsulter	30	156,8	30	50
	Utbildning + broschyrer	90	54,0	40	50
	Summa	**1726**	**1661,5**	1160	894
PR	Löner 195 kr/tim	117	177,5	186	175
	Resor ingår i standardlön	(15)	0,0	(30)	(25)
	Små inköp	5	0,0	10	10
	Summa	**122**	**177,5**	196	185
PF	Löner 250 kr/tim	114	58,1	250	285
	Resor ingår i standardlön	(15)	0,0	(30)	(25)
	Små inköp	5	1,7	10	10
	Summa	**119**	**59,8**	260	295
MN	Löner 330 kr/tim	211	147,7	200	153
	Resor ingår i standardlön	(15)	0,0	(30)	(5)
	Små inköp	5	0,0	5	10
	Summa	**216**	**147,7**	205	163
BEA	Löner	150	191,5	175	225
	Resor	50	55,0	40	60
	Summa	**200**	**246,5**	215	285
U	**Summa**	**0**	**86,8**	0	0
A	**Summa**	**0**	**8,2**	0	0
ALLA	**TOTALT**	**2383**	**2388,0**	2036	1822