# 1 INTRODUCTION

At the end of September 2009 the University of Manchester published on its website Professor Coggon's provisional report on the health risks from contamination of the Rutherford Buildings (Coggon, 2009). Accompanying this report was HPA's provisional report on the assessment of possible radiation induced health effects from contamination at the University of Manchester (Jones et al, 2009) and the Health and Safety Laboratory's report on the risk of health effects from mercury contamination (Rowbotham et al, 2009). Professor Coggon asked for comments on these reports by 11th January 2010.

This note gives HPA's response to the comments received on its provisional report and any other radiation-related comments. Where appropriate the original text and the marked comments are reproduced here together with HPA's response.

# 2 JOHN CHURCHER'S COMMENTS

**General comments**

**Absence of reliable radon-222 measurements prior to remediation**

As pointed out in the comments made by John Churcher, the radon-222 measurements in rooms 2.62 and 2.63 were made following remediation rather than prior to remediation as stated in the HPA provisional report. However the measurements in room 2.54 were made prior to remediation and therefore have been retained. Table C.9 and other relevant text in the report have been amended to make this clear. However, this does not affect the assessment of doses and risks as, due to the absence of more comprehensive data, the radon-222 concentration used in the assessment were based on the radium-226 contamination levels rather than these measurements.

John Churcher comments that 'no tests for radon progeny in glass have yet been undertaken, and the possibility is not mentioned in the provisional report'. As discussed with John Churcher and Professor Coggon previously, measurements of radon progeny in glass could be made to give an estimate of exposure from radon progeny. It should be noted that there would be uncertainty about the applicability of any measurements for use in the assessment. For instance, John Churcher has offered a glass picture frame which was in his office from the 1970s to 1990s for analysis. As an example of a possible uncertainty, it possible that before or after this time the picture frame was kept in rooms with higher radon levels. The benefit of the additional information provided by these measurements would need to be weighed up against the cost of making the measurements and consideration of the likelihood of these measurements affecting the conclusions of the assessment.

Radon-222 and its progeny result from the radioactive decay of the radium-226, the main radioactive contaminant found in the buildings and part of the uranium-238 radionuclide decay chain. Therefore measurements of radon-222 in air and its progeny

in glass are helpful in that they can be used to indicate a person's exposure resulting from the radium-226 contamination. However it should be noted that there are more direct methods by which an individual's exposure to radiation can be assessed. Measurements of radionuclides in the uranium-238 and the thorium-232 radionuclide decay chains in post-mortem samples of two members of staff who died of pancreatic cancer and radiation exposure levels in a tooth from a former member of staff indicate levels of exposure which are consistent with those found in the general population. The measurements reflect the direct exposure to individuals and are therefore of greater significance. HPA therefore does not feel that it is necessary to determine the levels of radon from measurements of the progeny in glass.

**Nature of ventilation system**

The assessment is generic in nature and is not intended to take account of the patterns of ventilation within the Rutherford building. Where possible, estimates of exposure, ie exposures following remediation of the buildings, have been made using passive radon detectors over 3 months as they will be most reliable indicators of radon levels in the rooms.

**Comments on HPA's provisional report**

*Executive summary*

Is this the same as the 'Whole chain case' (see p. 4)? If so, why the change of description, and why is it here described as representing "an upper bound of the possible levels of contamination"?

affected locations at the University. This information was then used to derive representative levels of contamination at a generic location which were used to estimate radiation doses and risks of radiation induced health effects. The aim was to calculate doses to hypothetical individuals from exposure to radioactive contamination that could have occurred in the past and from current exposure levels, in each case assuming a working lifetime of 40 years. As measurements of radioactive contamination were not available before 1999, assumptions had to be made to determine levels in earlier years (1950 to 1989 were considered) and a cautious approach was adopted to try to ensure that the risks were not underestimated. Two source terms were used in the study, one representing the more likely amount of radioactivity (referred to as the 'base case') and the other representing an upper bound of the possible levels of contamination. Remediation of the buildings was carried out between 2000 and 2004. Measurements made after the remediation were used to estimate the contamination levels for the assessment of exposure for current and future occupants.

Yes, the upper bound is intended to be the same as the whole chain case. The terminology was changed in the executive summary so that the purpose of considering this scenario would be clearer.

*Section 3*

This assumes no change in exposure routes. Building alterations, change in patterns of occupation, use, etc. could all result in significant changes in exposure routes.

For the assessment of past exposures HPA considered the doses and risks to people working in the building between the years 1950 and 2000. The year 2000 was chosen as the end point of the assessment of past exposures as the refurbishment of the Rutherford Building, which included the removal of radioactive contamination, began in this year. Following this remedial work the exposure levels would have been significantly reduced. The year 1950 was chosen as an early enough start point to include anyone who had worked in the buildings but who had now retired. In discussion with Professor Coggon, it was decided to assume a maximum working time in the buildings of 40 years. Therefore, results in this report are presented assuming that exposure occurred between the years 1950 to 1989, exposures between 1960 and 1999 would have been lower and so were not presented. It was thought that no individual had worked in the buildings over such a long time period and this is therefore an example of the cautious approach adopted in the assessment, considering the exposure of a hypothetical worker at the University rather than specific individuals.

It must be stressed that the assessment is intended to be representative of the highest exposure of typical occupants of the building. Generic values have been assumed for inadvertent ingestion rates, inhalation rates and occupancy of the rooms and no variation over time of these parameters has been assumed. It should be noted that these generic parameters are cautious, ie likely to result in higher doses than would be expected in practice. If variations in the exposure routes had been assessed the doses would not be higher than those reported. The report has been amended to make this point more clearly.

This ignores available evidence that the offices of Prof. EB Paul were re-plastered and re-painted in the early 1960s in order to remove radioactive contamination.

well as historical records that provided information on the work of Professor Rutherford and his colleagues with radioactive materials.

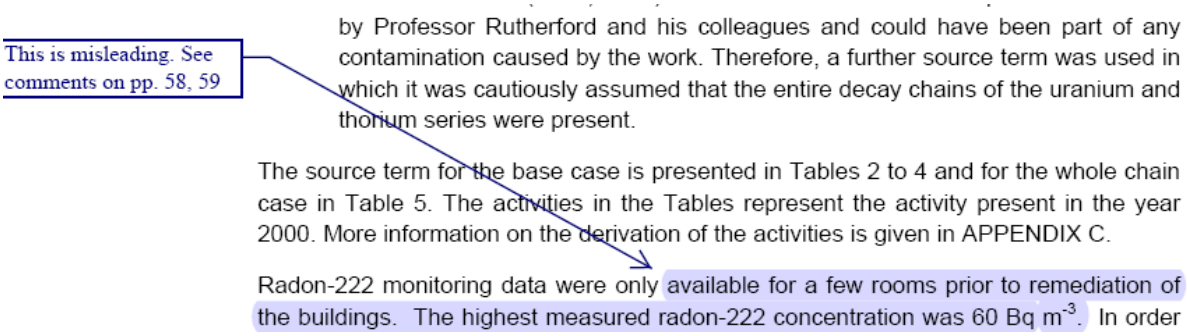
Unfortunately, monitoring records of radioactive contamination only exist for 1999 onwards. Information provided by the University (Peters, 2008) does not indicate that any substantial building work or remediation was carried out prior to 1999. Therefore, contamination levels measured before the refurbishment work were used to estimate the

The exposure group of main concern are those people (or persons) who spent the last few decades in the buildings before they were remediated ie those that were in buildings from the early 1970s until the buildings were remediated (1999). The assessment is mainly based on measurements made in 1999, decay corrected back to earlier years. John Churcher and his colleagues, who were present in the Rutherford Building from the early 1970s to 1999, have indicated that there was no substantial building or remediation work done during this time. In order to encompass a 40 year working lifetime exposures were nominally assessed for 1950 to 1989 taking account of radioactive decay. If remediation work was carried out in the 1950s or 1960s then exposures received before this remediation work might have been higher than those reported.

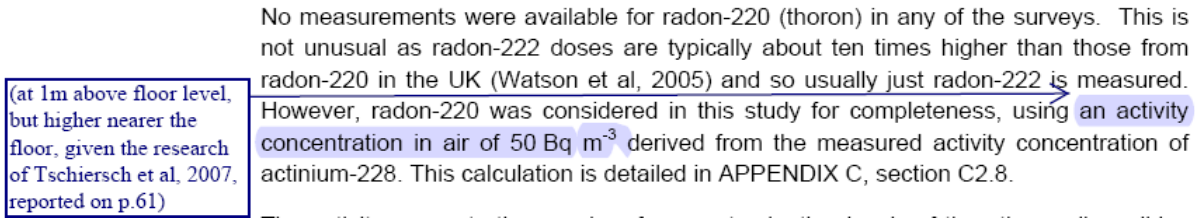
Although there is anecdotal evidence of replastering and repainting of Professor Paul's office in the early 1960s this is not felt to have been substantial building work or remediation.

The report has been amended to reflect both comments made above.

*Section 4*

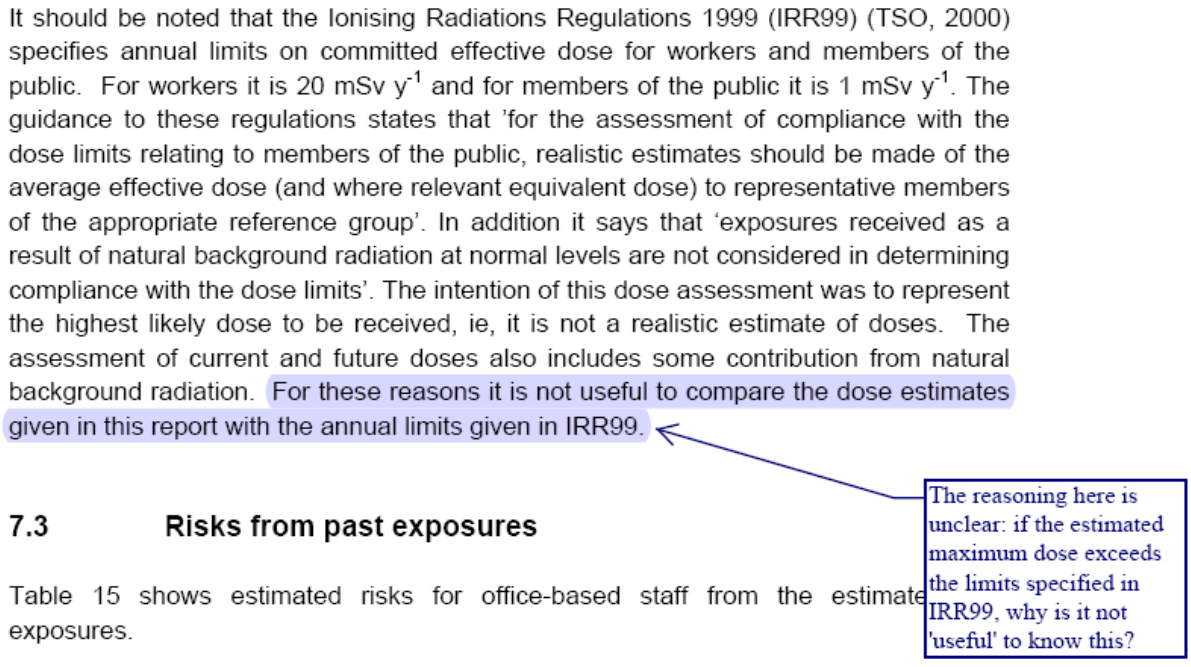



See comment on page 1. This text has been amended.




The report has been amended to say 'activity concentration in air of 50 Bq $m^{-3}$ at 1 m above floor level'. The additional text is already included in the Appendix.

*Section 7*



This paragraph has been expanded to explain that although it is of interest to compare the doses estimated with the dose limits for the public and workers they are not directly applicable for the reasons discussed.

*Section 8*

False comparison, because 60 Bq m-3 is not a pre-remediation measure.

- The highest reported contamination values have been assumed to apply to all of the decay chain being considered (except for thorium-230 and actinium-227 for the base case, as discussed in section 4.1). For example, in all of the rooms except one, which was probably used for lead-210 experiments, measurements of radium-226 progeny were found to have lower values than those for radium-226; probably due to the escape of radon-222 gas. However, to estimate doses it was assumed that the progeny were in equilibrium with radium-226. Another example of a cautious assumption is that a radon-222 gas activity concentration of 180 Bq $m^{-3}$ was estimated from the historical inventory, whereas the highest measured radon-222 concentration prior to remediation was 60 Bq $m^{-3}$, a factor of three lower.

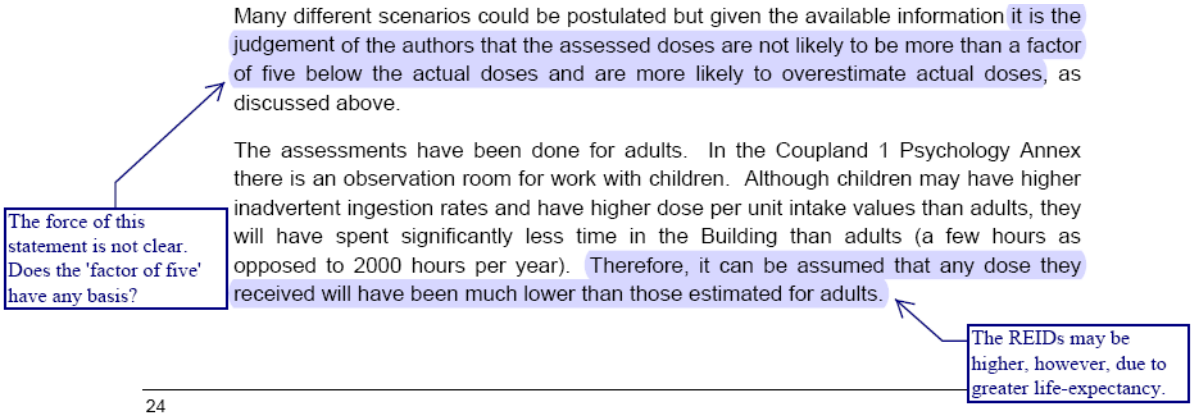
This has been removed and replaced with another example as 60 Bq $m^{-3}$ is a post remediation measurement..

This ignores available evidence that the offices of Prof. EB Paul were re-plastered and re-painted in the early 1960s in order to remove radioactive contamination.

for the expression of the risk. In addition, the annual doses used were committed organ doses which are integrated over a 50 year period. For long-lived radionuclides that are retained in body organs over many years, dose is received over many years and assigning dose to the year of intake will overestimate risks.

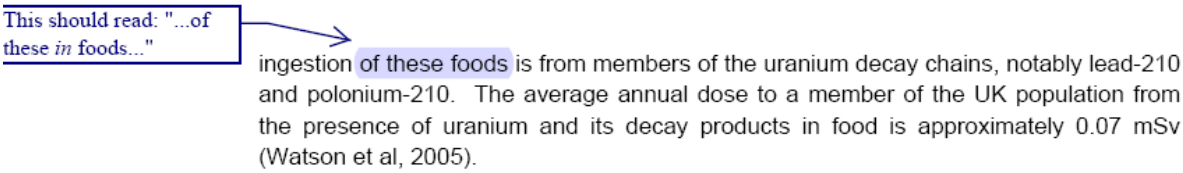
While there are good reasons to believe that doses have been overestimated, it is possible that if remediation had been carried out at some earlier time contamination levels in the past could have been higher than indicated by recent monitoring. Information provided by the University (Peters, 2008) did not indicate that any substantial building work or remediation was carried out prior to 1999, although there was some documentation (see section C2.13) which surmised that some sanding of the floors may have occurred.

See the response on page 3



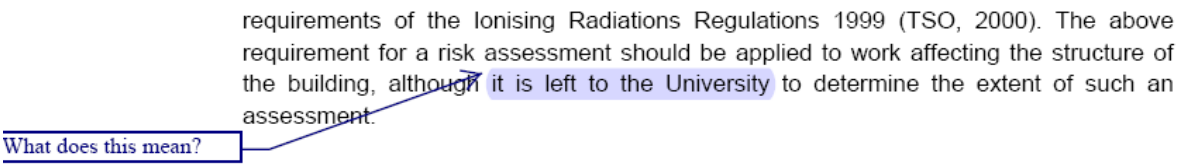

The factor of five is based on the information available and the judgement of the authors based on their experience of previous assessments. In our judgement the doses are unlikely to be underestimated by more than a factor of 5 and certainly not by orders of magnitude.

Addressing the second point, the REID per unit dose will be slightly higher for children but their doses will be significantly lower than those for adults as they will have spent significantly less time in the Building. Therefore the REID for children is likely to be lower than for adults. Additional text will be added to the report to make this clear




This has been changed to 'The most significant contributor to the dose from the ingestion of *these naturally occurring radionuclides in foods..'.*

*Section 9*




It was intended to mean that the detail of the risk assessment would need to be proportionate to the extent of the work. As this would depend on the specifics of the situation HPA is not in a position to provide specific advice. The paragraph has been reworded to make this clear.

*Appendix B*

In the monitoring reports, detailed in APPENDIX C, room numbers have been given. Table B.1 summarises the room names or numbering for the rooms of interest from these monitoring reports.

The table appears to be incomplete. What about rooms on the 2nd floor, such as 2.62, 263, 2.52, 2.53?

**Table B.1 Different names of rooms over time identified in the monitoring reports as being the most heavily contamination**

| | Name of the building | | |
|---|---|---|---|
| | Physical Laboratory | Coupland 1 Building | Rutherford Building and Manchester Museum |
| | 1900 | 1968 | Present day |
| Basement | Liquid air and research | CB04, CB05 and CB07 | B55, B58 and B57 (Manchester Museum) |
| | Research (29.2 x 23.5) | CB09 | B62 (Manchester Museum) |
| | Research (27.10 x 19.3) | CB10 | B63 (Manchester Museum) |
| Ground floor | Private laboratory (28.0 x 19.7) | G54 and G55 | G.055 (Rutherford Building) |
| First floor | Balance room (20.10 x 16.6) | C1.10 | 1.51 & 1.52 (Manchester Museum) |

These rooms on the second floor were less heavily contaminated than those included in the Table. However, since the external gamma dose rates measured in these rooms post remediation were used in the assessment they have been added to this Table.

*Appendix C*

Professor Schuster's radium remained out of the original 60 to 70 mg. However, the difference between these amounts was unlikely to be due to loss through spills, but rather that it was unavailable for use by Professor Rutherford as it was being used in other experiments. It is known that accidents occurred but information is not available on the amount of material lost. There was difficultly in obtaining radium at this time and it is

What is the basis for this conjecture?

This inference was based on the information provided by Todd (2008), page 21

'On 5th October 1907, Rutherford had formally applied to the Kaiserliche Akademie der Wissenschaften of Vienna for a loan of "about half a gram of pure radium". He notes in the letter that the University at this time has "less than 30 milligrams of radium bromide" (that leaves 30-40 mg unaccounted for, presumably in use by Makower and co-workers).'

The report has been amended to make clear that an inference has been drawn and note its source.

**C1.3 Estimate of surface contamination levels based on historical inventory**

Although monitoring data were available for radium-226, this was not the case for thorium-230 and actinium-227. Therefore, contamination levels for thorium-230 and actinium-227 were derived from the historical inventory. A relationship between the

Not pre-remediation

Monitoring data pre-remediation were available (Robinson, 2000 and Adams, 2000). Additional text has been added to this paragraph to include these references.

What is the source for these figures?

**Table C.2 Comparison of measured and estimated surface contamination levels**

| | Estimated inventory in 1903 (Bq) | Surface contamination in 1903 assuming 0.1% lost ($Bq/cm^2$)[a] | Surface contamination in 1903 assuming 1% lost ($Bq/cm^2$)[a] | Estimated contamination levels in the year 2000, used in this assessment ($Bq\ cm^{-2}$ and $Bq\ g^{-1}$) | Measured surface activity concentration in the year 2000 |
|---|---|---|---|---|---|
| Radium-226 | $1.2\ 10^{10}$ | 6<br>(60) | 60<br>(600) | **200** | 20 - 87 $Bq\ cm^{-2}$<br><1 – 200 $Bq\ g^{-1}$ |
| Thorium-230 | $2\ 10^{8}$ | 0.1<br>(1) | 1<br>(10) | **10** | N/A[b] |
| Actinium-227 | $1\ 10^{9}$ | 0.5<br>(5) | 5<br>(50) | **10**[c] | N/A[b] |

(a) Values are those based on a floor area of 200 $m^2$, with the values in brackets being based on a reduced floor area of 20 $m^2$

(b) No monitoring results were available for these radionuclides and their activity in the year 2000 was based solely on the estimated inventory in 1903.

(c) The activity of actinium-227 present in the year 2000 is approximately a factor of 17 less than that present in the year 1903 due to radioactive decay, this was rounded up to 10 Bq $cm^{-2}$ for use in the assessment.

The surface contamination measurements were inferred from the information provided by Robinson (2000) and the activity concentrations were as given by Turner (2000). These references will be added to the table.

From Table C.2, it is seen that the measured levels of radium-226 indicate that the percentage of activity lost and the floor area affected was likely to be within the ranges assumed. To estimate the contamination levels for thorium-230 and actinium-227, it was cautiously assumed that 1% of the total activity was distributed over a floor area of 20 $m^2$, with the values rounded up to the next order of magnitude.

Is the assumption being made here that the proportion of Ra-226 lost through spillage was between 0.1% and 1%? On the basis of Neil Todd's research it seems possible that considerably more than 1% may have been lost in this way.

## C2 USE OF MONITORING DATA

This section summarises the monitoring data used for the assessment. The data were obtained from monitoring reports made available to the HPA.

The estimated contamination for all of the radionuclides considered in the assessment, with the exception of thorium-230 and actinium-227 are derived from measurements in 1999/2000 prior to the remediation work. In addition, the proportion of radium-226 by activity spilled was estimated so that this proportion could also be applied to the estimated historical inventories of thorium-230 and actinium-227 for which no measurements were available. The relationship between the historical inventory and the surface contamination measurements is dependent on the assumptions made of the proportion of activity spilled and the floor area. The intention was to give an indication of the relationship rather than provide a definitive answer as to the proportion of activity spilt. Spillage of a larger proportion could be assumed but then in order for the inventory to tie in with the measurements in 1999/2000 it would need to be assumed that the material was spilled over a larger area or that remediation had taken place to remove some of the contamination. Additional text has been added to the report to make this clearer.

the major remediation work known to have been carried out. Information provided by the University (Peters, 2008) indicated that, although the usage of rooms changed over time and there may have been some associated renovation of the rooms, there was no evidence of major building work or remediation prior to 2000.

This ignores available evidence that the offices of Prof. EB Paul were re-plastered and re-painted in the early 1960s in order to remove radioactive contamination.

**Table C.3 Summary of dates of major building work**

| Building | Date |
|---|---|
| Coupland 1 (CB05, CB09, CB10, G54/G55, C1.10 and 2.52/2.53) | 2000 |
| Basement of Coupland 2 | 2001 |
| Coupland 1 – Cohen Lecture Theatre | 2002 |

See response earlier in the document.

Annotated pages from HPA

This document has not been made available to us. Is it possible see a copy?

APPENDIX C

**C2.1 Gamma spectrometry results prior to remediation**

*Analysis of Manchester University Museum sample, 5 April 2000 (NIRAS, L2000047, (Turner, 2000b)*

This comment is for the University to address. Kelly Jones did inform John Churcher in an email on 24/6/09 that HPA had this report.

There has been a transcription error here. The error range should be ± 0.094

**Table C.6 High resolution gamma spectrometry measurements (Turner, 2000a)**

| | Activity concentration (Bq g$^{-1}$) | | |
|---|---|---|---|
| | Under floor dust from room G55 between joists 2-3[a] | Wall sample from room C.1.10, Local contamination[b] | Brick/mortar dust from brick 5/6, Under window, Room CB 05[c] |
| **-238 decay chain** | | | |
| Ra-226 | 70.1 ± 7.7 | < 5.5 | 53.7 ± 8.3 |
| Pb-214 | 0.44 ± 0.31 | < 0.39 | 12.20 ± 0.73 |
| Bi-214 | 0.9 ± 0.32 | 1.00 ± 0.49 | 14.41 ± 0.65 |
| Pb-210 | - | 4103 ± 677 | - |
| **Th-232 decay chain** | | | |
| Ac-228 | 0.571 ± 7.7 | 0.243 ± 0.094 | 0.81 ± 0.24 |
| Pb-212 | < 0.43 | < 0.38 | < 0.40 |
| Bi-212 | < 3.7 | < 2.6 | < 2.4 |

(a) NIRAS reference L2000103-70
(b) NIRAS reference L2000103-85
(c) NIRAS reference L2000103-92

The report will be amended to give the correct value.

These measurements were *not* made prior to remediation. Large quantities of contaminated material had been removed in 2000-2001.

in 2002.

**Table C.9 Radon-222 measurements made in Rutherford Building prior to remediation**

| Room | Measured radon-222 concentration Bq $m^{-3}$ |
|---|---|
| Room 2-54 2m | 23.37 |
| Room 2-54 Centre of Room 1m | 27.44 |
| Room 2-62 Centre of Room 1m | 56.91 |
| Room 2-62 centre of Room 2m | 59.96 |
| Room 2-63 Centre of Room 1m | 28.46 |
| Room 2-63 Centre of Room 2m | 34.04 |

The highest measured radon-222 concentration was approximately 60 Bq $m^{-3}$.

Measurements for rooms 2-62 and 2-63 were made following remediation and the report has been amended to reflect this.

*Not* pre-remediation.

Radon-222 monitoring data prior to remediation were only available from the Rutherford Building (Rooms 2.54, 2.62 and 2.63) (see section C2.4). The highest measured concentration in air was approximately 60 Bq $m^{-3}$. No measurements were available for radon-220 (thoron).

See above comments. The report has been amended.

This implies that the remainder of the radon never escapes, but instead decays to Pb210, Po210, and Pb208 which remain trapped in the material. Has this 'retention fraction' been used in estimating expected ratios of Ra226 to Pb210?

or = $(7.12\ 10^{4}\ s^{-1} * 1.2\ 10^{-2}\ s^{-1} * 0.5 * 3.6\ 10^{3}) / 1.0 * 300\ m^{3}$

= 5100 Bq $m^{-3}$ (for radon-220)

The ability of radon-222 or radon-220 gas to leave a material is related to a parameter termed the emanation fraction. The value of this parameter will depend on the material with which radium has become associated with. Recoil effects, combined with the time it takes free radon atoms to diffuse through the medium in relation to its short half-life, act to reduce the proportion of radon that can escape from the material. In this case it was assumed that the contamination was due to radium in solution soaking into the top layer of the wooden floor. Although the emanation of radon from various media, including materials used in the construction of buildings, has been studied extensively, no data exists for absorbed radium liquid. HPA (Dixon, 2009) gave a conservative estimate of the emanation fraction of 0.3 - 0.5 for radium solution absorbed by wood. In this

No, two separate but cautious assumptions were made. When estimating the surface contamination levels for both the base and whole chain case it was cautiously assumed that none of the radon progeny such as bismuth-214, lead-210 and polonium-210 had escaped ie that 100% of the contamination remained. However, when estimating radiation doses from inhalation of radon gas an emanation fraction of 0.5 was assumed, meaning that 50% of radon and its progeny had escaped.

# 3 NEIL TODD'S COMMENTS

(1) The assumed 1% loss rate underestimates the unaccounted for Schuster radium.

See response on page 8.

(2) The historical evidence strongly indicates that significant remediation did take place before 1999, contrary to the assumed absence of prior remediation.

See response on page 3.

(3) The historical evidence also indicates that prior levels of contamination were significantly higher than has been assumed.

The information contained in Neil Todd's note does not provide evidence that the prior levels of contamination were higher than has been assumed. The pitchblende residues would have been likely to contain only relatively minor amounts of radium (which are not quantifiable). Although information received after the report was completed indicates that Rutherford may have held radium sources for calibration for external parties, they were not in a form likely to lead to significant loss and therefore omission from the inventory would not make any significant difference to the amount of contamination estimated. Therefore these sources do not significantly increase the activity estimated above for the total amount of radium in Rutherford's inventory, 12 GBq, assumed in Jones et al (2009). It should also be noted that the estimated exposures from radium-226 contamination were based on measurements and not the estimated radium-226 inventory.

(4) In addition to known hotspots of Pb210, there was likely to be a wider more diffuse Pb210 contamination, due to leak of radium emanation with tube breakage, which is not included in the contamination scenario. This issue could be resolved if further measurements were made using appropriate instruments, i.e. which were sensitive to low-energy gamma-rays. The currently planned further remediation work in 2.62/2.63 provides an opportunity for this to be done.

It would be expected that the radon progeny such as lead-210 would not be in equilibrium with the radium-226 as a significant percentage of radon gas would escape through natural ventilation of the buildings. Regarding the breakage of emanation tubes a significant percentage of the radon gas contained in the tubes would escape from the buildings and any radon progeny which had plated out on the glass would have been thrown away with the glass. The measurements indicate that at the time of remediation the radon progeny were present at about one third or half the level of the radium-226 contamination. However in the assessments it has been cautiously assumed that the radon progeny were present at the same contamination levels as radium-226.

(5) The contamination was heterogeneously distributed contrary to the homogeneity assumption in the risk assessment.

It is agreed that in reality the contamination was distributed heterogeneously. However the purpose of the assessment was to be representative of the highest exposures that may have been received rather than to estimate exposures related to specific rooms. In doing a generic assessment a homogenous patch of 1 $m^2$ was assumed which is larger than the patches of contamination indicated in monitoring reports. The assessment also cautiously assumes that this area is contaminated at the level of the highest measurement made. It must be stressed that contamination levels for all radionuclides except thorium-230 and actinium-227 were derived for measurements and not based on spillage rates. Additional text has been added to the report to acknowledge that the contamination was not homogenous and to more clearly explain the purpose of the assessment.

(6) Data from decommissioning of the Cavendish Laboratory Radium Room in 1958 provide a good model for estimating contamination levels in the Manchester Radium Room in 1919.

The HPA team were aware of the information from the Cavendish laboratory. However for the purposes of assessing exposures to people occupying the building in the recent past (early 1970s to 1999) the contamination levels present in the Manchester buildings in 1919 are not useful. As Neil Todd points out on page 9 of his comments 'it is quite likely that there were previous attempts to clean up the contamination after Rutherford in 1919'. The amount of contamination found in the Cavedish Laboratory in 1958 cannot be extrapolated to the University of Manchester because different amounts may have been spilt and different amounts may have been cleared up.

Neil Todd makes a final comment that mass spectrometry could potentially distinguish whether the radium is Schuster's pure RaBr2 or Rutherford's impure RaBaCl2. Although of interest from a historical perspective, in terms of assessing the impact of human health this has little relevance.

# 4 UNIVERSITY OF MANCHESTER UNIVERSITY AND COLLEGE UNION COMMENTS

*3. The report suggests that the findings of an epidemiological study would be subject to 'substantial statistical uncertainty' (p.9). However we suggest that this is also the case for the findings of the risk assessment, given the necessary reliance at times on hypothetical estimates of spillages of radionuclides and mercury. For example, how would the risk estimation differ if, say 5-10% of radionuclides were spilled during the early years of the buildings use, rather than the 1% figure cited in the report?*

See response on page 8.

# 5 REFERENCES

Adams S (2000). Residual contamination survey of Coupland 1 Building, the Annexe and the Old Dental Hospital. NIRAS MTC/2000/051, Issue 02.

Coggon D (2009). Health Risks from Contamination of the Rutherford Building, University of Manchester - Provisional Report.

Jones KA, Oatway W.B., Haylock RGE et al (2009). Assessment of the possible risks of radiation induced health effects from contamination at the University of Manchester - Provisional Report. RPD-EA-10-2009.

Robinson KJ (2000). University of Manchester Museum Building Coupland 1. University of Manchester.

Rowbotham A, Gibson R, Easterbrook A and Cocker J (2009). HSL contribution to the investigation of the Rutherford Laboratories at Manchester University - provisional report. Report Number AS/2009/15 .

Todd N (2008). Historical and radio-archaeological perspectives on the use of radioactive substances by Ernest Rutherford. Interim version 1.

Turner JD (2000). Analysis of Manchester University Museum sample. Warrington, L2000047.