Literature Review prepared by Kerry Hansford for:

AUSTRALIAN WOOL INNOVATION PROJECT - EC573

Managing the Risk of Dark and/or Medullated Fibre Contamination

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TABLE of CONTENTS

1. PROJECT BACKGROUND

This project was initiated in response to on-going concern by members of the Federation of Australian Wool Organisations (FAWO) over contamination of the Australian wool clip by dark and/or medullated fibres. Funding was sought from and provided by Australian Wool Innovation (AWI) as one of its initiatives to address the contamination issue. It is anticipated that the project outcomes will be useful in countering alarm about the degree to which the Australian Merino clip is contaminated, thereby protecting its high standing.

A manual method of measuring dark and/or medullated fibre contamination in a scoured core-sample is commercially available[1,2]. While equipment costs are low, labour costs are high (~4 hours/test), thus it is unlikely to be commonly used. AWI is currently funding three research groups to develop improved methodologies for measuring this form of contamination.

The sampling required for different sources of contamination requires clarification. Research has shown that dark and/or medullated fibres in the wool from Merinos that have been in contact with exotic[a] sheep or have raised an exotic cross lamb can be detected using a core-sample. In contrast, core-sampling does not provide a representative sample of urine-stained and isolated pigmented fibre contamination due to its discrete nature. Thus, any test based on a core-sample will not work for dark fibre originating from these latter sources.

Woolclassers/growers are urged to declare lots that contain dark fibre by using a "Y" qualifier in the description. However, there is no method to declare the risk of dark and/or medullated fibres as negligible. To protect the Australian Merino clips' reputation, tools are required to control/manage the risk of unwanted delivery of dark and/or medullated fibres. Equally, white wool Merino producers would like the opportunity to identify their product as such.

The prediction of dark fibre contamination was proffered by Roger Foulds of CSIRO in 1988[3], with its principles later utilised in wool quality schemes (eg. Clipcare, Dalcare). Thus, FAWO proposed that a voluntary vendor declaration for the risk of dark and/or medullated fibre contamination be investigated, and if viable, reported in sale catalogues and test certificates.

A dark and/or medullated fibre risk (DMFR) scheme would provide: (a) an interim approach pending a low cost Pre-Sale Test and (b) on-going information on the risk of traditional urine-stain and pigmentation. The tasks involved in this project are summarised below.

1.1. Summary of Project Activities

The CSIRO Dark Fibre Risk Scheme will be updated to include data on the contamination risk related to exotic breeds. Activities to facilitate and support the introduction of a vendor declaration for dark and/or medullated fibre contamination will include:

- Practical methods that allow growers to declare information to determine a DMFR and transfer it to broker/private treaty merchant and test house.
- Submissions to the Australian Wool Exchange (AWEX) and the International Wool Textile Organisation (IWTO) proposing that the DMFR Factor is reported in Sale Catalogues and on Test Certificates.
- Objective tests on sale lots covering a range of Risk categories to validate the scheme and to develop a sampling regime for future testing system(s).
- Industry seminars to guide and promote the introduction of the Risk Scheme. Written material will aid communication with producers and the trade.
- An industry-working group to ensure the interests of all sectors is considered. The group will contribute to any related or subsequent projects.

[a] For the purposes of this report, "exotic" refers to sheep breeds that shed pigmented and/or medullated fibres and are allocated an AWEX Risk Rating of 5. Currently, these breeds are Awassi, Damara, Dorper, Karakul and Wiltshire Horn. Note: The Wiltshire is used for carpet-wool production, not as a meat breed.

2. REVIEW OF LITERATURE

Note, this literature review has been undertaken to ensure that all aspects related dark and/or medullated fibre contamination are considered and to avoid duplicating previous research.

Contamination of the Australian wool clip may be classified according to its origin. One simple classification defines contamination as being of wool or non-wool-origin. The categories of wool-origin contamination are urine-stained, pigmented and medullated fibres. Non-wool contaminants include vegetable matter and other animal fibres (eg. dog or horse hair, alpaca fibre), as well as man-made products such as wool packs, baling twine, fertiliser bags, other yarns and fabrics, etc. This review is concerned with clip contamination of wool-origin, collectively termed "dark and/or medullated fibres".

The problem of dark and/or medullated fibres in the Australian wool clip was acknowledged by Alfred Hawkesworth, the 1891 founder of the Sheep and Wool Department of Sydney Technical College, in his textbook on Australasian Sheep and Wool[4]. In the 7^{th} edition, he wrote that when judging stud Merino rams or ewes that the head, face, hoofs and legs should "be free from black or brown spots" and that the fleece should have "no undue roughness or hairiness". Furthermore, that "if two sheep are of equal merit otherwise, the one with the least number of spots would take precedence". With reference to stained wool, he wrote, "When wool is black or brown, caused by urine, it is called stained. This defect is totally impossible to prevent, and however carefully the wool is scoured, it always has a burnt appearance……..The wool is used in the making of fabrics of the darkest colours".

These concepts were placed in context when he asserted that buyers and manufacturers favoured "well-got-up" clips, where skirting and sorting resulted in white fleece wool free of black and grey wool, and pieces and bellies picked for stain. In this situation, the manufacturer could direct categories of wool to the most appropriate end-use, be it "light, white coloured goods" or fabric "dyed into darker shades or colours than wool itself".

In the section on "Faulty Wools", Hawksworth says of kemps "these are most objectionable fibres, the cells having collapsed, which accounts for the hard and brittle nature, and should not be found on a Merino sheep, but when present are on the head mostly, sometimes on the britch, and have a very damaging effect. To manufacturers, kemps are detestable, as their nature prevents them from being successfully used, as in the course of manipulation they break off short, and resist dyes".

One hundred years later, although scientific understanding of dark and/or medullated fibre contamination has advanced, it remains a serious problem for both producers and users of Australian wool, with the issue further complicated by the increased use of exotic breeds by the Australian sheep meat industry.

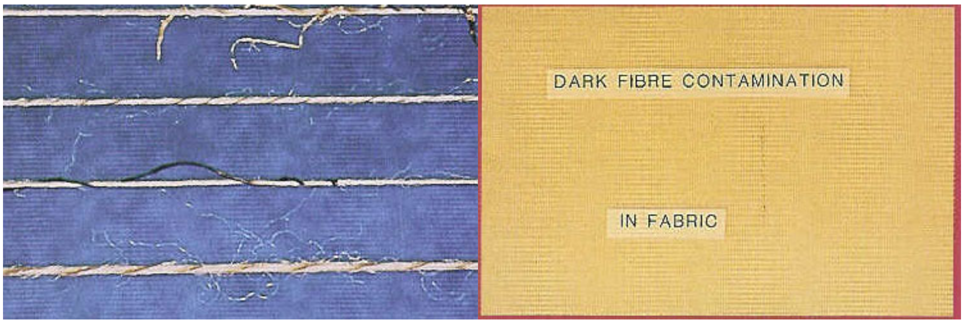
2.1. The Problem

2.1.1. Contamination by Dark Fibres

Dark fibre contamination causes problems for the manufacturer[5]. A single dark fibre in a white/pastel fabric will appear as a thin dark line if lying on the surface of the yarn (see Figure 1), or as a dark smudge if it lies within the yarn structure. Although dark lines are more noticeable in woven yarns, and dark smudges in knitted yarns, all fabric structures can be affected. To rectify this situation after weaving involves manual removal (picking) of the individual dark fibres or, if the contamination levels and thus the picking costs are too high, then the fabric may be dyed to a darker shade.

In 1984[5], the cost of picking ranged from 10 cents per kilogram to prohibitively expensive depending on the type of garment, fabric structure and location of the mill. Picking is not undertaken when it is uneconomic or if the appearance of the fabric may be damaged during the process. If contamination in a fabric is too high, then compensation for financial loss is claimed on the spinner, who subsequently makes a claim on the topmaker. Such claims range from the total replacement cost of the fabric to a share of the picking costs to remedy the problem.

Figure 1 Dark fibre contamination in yarn and worsted fabric (Source: CSIRO[6])



Although specially designed trials have not been conducted, there is no evidence to suggest that dark fibres, either urine-stained or pigmented, are lost during processing. In one experiment[7], the number of dark fibres in tops was found to be higher than that of the greasy fleece; however, fibre breakage during topmaking and the poor detection of fibres in the greasy wool is believed to contribute to this discrepancy. In their trial, Hatcher *et al.* (1999)[8] did not find any such increase in contamination and believe that contaminant fibres that are of similar structure to wool do persist in worsted processing and will appear as faults in the top and fabric. It was further postulated that dark fibres would persist in the woollen system due to its less efficient carding and combing process[9].

Identification of dark fibre contamination in a sale lot prior to sale would give a buyer the opportunity to purchase wools suited to their proposed end-use. In this way, wools destined for white/pastel end-uses could be contamination free or nearly free. Although a manual guidance test for the measurement of dark fibres in a core sample is available[1,2], Pre-Sale Testing for dark fibres of urine-stain and pigmentation origin is not feasible because:

- only a very small quantity of dark fibres is required to produce a recognised fault; that is, approximately 4 staples in 1 bale or 10 g per tonne of wool, and
- its distribution is non-random; that is, it generally occurs as discrete clumps within a fleece and subsequently a bale, thus making core or staple sampling unrepresentative.

Despite the lack of a Pre-Sale Test, processors often specify a limit for dark fibre contamination (eg. <100 dark fibres/kilogram for white/pastel end-uses). Therefore, in order to meet a spinner or weaver's dark fibre limit, buyers/topmakers are reliant on their knowledge of the source and extent of dark fibre contamination for specific categories of wool (see Section 3.1.3).

On the other hand, the dispersion of dark fibres in the fleeces of exotic breed sheep and Merinos run with exotic breeds or their crosses is random, thus core sampling provides a more representative sample. However, due to the manual nature of the current guidance test[1,2], routine testing of sale lots is not commercially feasible.

Given these circumstances, the buyer is dependent on the accuracy of the information obtained from the grower and/or woolclasser. In 1998[10], the Australian Wool Exchange (AWEX) changed the Code of Practice to incorporate quality control procedures that recognise not only urine-stained and pigmented fibres, but also the potential transfer of dark and/or medullated fibres from exotic breeds to Merinos. As well as adherence to quality standards for clip preparation, the AWEX Code of Practice advocates that a "Y" suffix be marked on the bale if the following criteria are met[11]:

- sheep that have been in contact with exotic breeds (Risk Rating 5), which carry pigmented fibres, within two months prior to shearing: OR
- ewes that have reared exotic crossbred lambs within the wool growth period.

In the AWEX ID Appraisal Guidelines[12], qualifiers are used to identify the presence and degree of contamination by pigmented, medullated or stained fibres. Table 1 lists the qualifiers used in this appraisal system.

Table 1 AWEX ID Appraisal Guidelines[12]. Qualifiers for use with dark and/or medullated fibre contamination

Qualifier	Description
Y1	Pigmented fibres in small amounts (1 or more fibres) or where there is an identified risk of pigmented fibre contamination, although pigmented fibre may not be visible in the sample.
Y2	Larger numbers of pigmented fibres are evident.
Y3	Prepared as a black (pigmented) line or a mixture of pigmented and white wool or large numbers of pigmented fibres.
P1	Odd/floating kemp.
P2	Medium/soft kemp.
P3	Heavy/harsh kemp.
S	Dark stain (urine and dung).

Note, grower and classer knowledge of the Code of Practice and Appraisal Guidelines was enhanced by the compulsory Woolclasser Development Program facilitated by AWEX in 2001/2002.

2.1.2. Contamination by Medullated Fibres

The problem of medullated fibre contamination is converse to that of dark fibres[13]. In fabrics that are coloured, medullated fibres give a different appearance when dyed. This problem is more pronounced as the depth of colour increases, that is, as the contrast between medullated fibres and others becomes more obvious. The least noticeable effects are in pastel shades. Medullated fibre contamination differs from dark fibre in that it is often not detected until the fabric stage, after dyeing.

If a fabric is already dyed a dark shade, then picking (see Section 3.2.4) is the only remedial action. However, if the contamination is detected prior to dyeing, a processor may be able to rectify the problem by changing the colour/shade of the fabric or using the wool in a fancy yarn[14]. Similar to the situation for dark fibre contamination, the cost of picking can be prohibitively expensive. Equally, if the level of contamination is too high, then compensation for financial loss is claimed from the spinner, who subsequently makes a claim on the topmaker.

The persistence of medullated fibres during processing is different to that of dark fibres[8,9]. Studies have found that animal fibres that are structurally different to wool, such as coarse medullated fibres and hair, were to some degree removed during worsted processing. This was consistent with previous research[15,16] which found the low strength of medullated fibres resulted in considerable fibre breakage during topmaking, with the coarser of these fibres being removed in card and comb waste. That said, contamination of noil might not be a welcome outcome.

Guidance Pre-Sale Testing (based on a core sample) is available for medullation; however, due to its high cost, uptake is low. In some circumstances, medullated fibres are randomly distributed over a fleece (eg. exotic sheep, or Merinos in contact to exotic sheep). For Merinos and some other breeds, medullation is more often found on the points; therefore, sampling to test for medullation is problematic.

It is not common for a processing specification to include a limit for medullation[9]. This suggests that medullated fibre contamination has previously been less of a problem to the manufacturer than contamination by dark fibres. This may be partly due to:

- The Merinos' inherent low levels of medullation,
- Buyers' recognition that non-Merino breeds present a medullated fibre risk,
- Loss of a proportion of medullated fibres due to fibre breakage during topmaking, and
- Although it is rarely used, a "P" qualifier in the AWEX ID of Merino wool identifying clips containing kemp.

Despite this, members of the Australian and international wool industry are alarmed at the increased occurrence of medullated fibre contamination, which has coincided with the expansion of crossbreeding, particularly Merinos with exotic breeds. This concern is borne out by recent commercial cases of medullated fibre contamination originating from Australian consignments of Merino wool[14,17].

2.1.3. Extent of Dark and/or Medullated Fibre Contamination

As a rule of thumb[5,18], the commercial limit for dark fibre contamination in tops destined for a white or pastel end-use is 100 dark fibres per kilogram (df/kg) with lower levels required for ultra-high quality products. One hundred df/kg equates to approximately three dark fibres per running metre of fabric. In 1993[19], CSIRO surveyed 116 commercial consignments comprising fleece and non-fleece blends of Australian wool to quantify the incidence of urine-stained and pigmented fibres. For a variety of wool categories, the average number of dark fibres per kilogram, classified as urine-stained or pigmented, is presented in Table 2.

Table 2 Relative incidence of urine-stained and pigmented fibres in Australian consignments (Source: Burbidge *et al.* 1993[19])

Wool Category highest to lowest %	No. Cons.	Number dark fibres per kilogram		
		Stain*	Pigment*	Total Stn*+Pig*
Flc	34	53	37	90
Pcs	12	247	65	312
Flc/Pcs	19	48	36	84
Flc/Pcs/Lms	2	146	731	877
Pcs/Bls	13	1,051	120	1,171
Pcs/Lms/Bls	2	1,212	597	1819
Bls/Stn/Pcs	1	58,461	0	58,461
Flc/Wnr	13	69	25	94
Wnr/Flc	3	126	126	252
XB	4	196	1,919	2,115
Flc/Mx	8	32	24	56

* Dark fibres colour graded as medium or dark according to IWTO DTM-13-01[20]

The data shows that the lowest concentration of dark fibres occurs in consignments of fleece wool only or those containing a high proportion of fleece wool. As the proportion of pieces and bellies increases, so does the dark fibre contamination, particularly of urine-stain origin. Although the number of consignments was limited, it is evident that as the proportion of lambs or crossbred wool increases, so does the dark fibre contamination; however, the greater proportion is pigmented fibre.

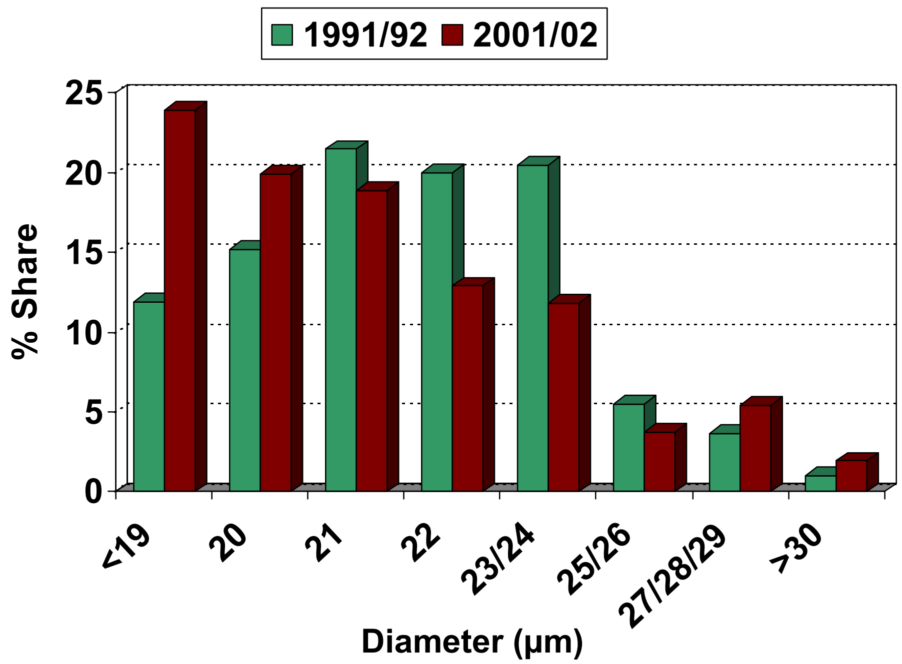
These findings are consistent with industry practice, where for consignments destined for restrictive white/pastel end-uses, buyers try to purchase better quality Merino fleece wools to minimise the risk of dark fibre contamination and a potential claim.

Limits are not generally applied to medullated fibre contamination in wool. However, in high quality mohair, 0.3% is considered objectionable. Without research or commercial clarification, it might be assumed that limits for medullation be similar to those for dark fibres (ie. 100 contaminant fibres/kg). This issue requires further investigation.

The last decade has seen an expansion in production of exotic breeds (eg. Awassi, Damara, Karakul, Dorper) for meat production, with the rams of these sheep often crossed with Merino ewes to more rapidly increase flock numbers[21,22]. This is confirmed by the wool statistics comparing the micron profile of wool offered at auction in 1991/92 with 2001/02 (see Figure 2)[23]. Three trends are discernable:

- Increase in production of wool ≤20 μm (44% cf. 27%).
- Decrease in production of mid-micron wool 21-26 μm (48% cf. 68%).
- Small increase in production of non-Merino types ≥27μm (8% cf. 5%).

Figure 2 Change in micron profile of Australian wool offered at auction, 1991/92 and 2001/02 (Source: Australian Wool Production Forecast Report, March 2003[23])



The increase in production of coarser non-Merino breeds is small compared to the change between fine and medium wool Merinos; however, it is still significant. Starting from a low base, the number of non-Merino sheep in Australia has increased by approximately 60% over the last 10 years, with a proportion of this due to the introduction of exotic breeds. These changes coincide with anecdotal evidence of increased contamination by medullated fibres in Australian wool[14,17].

However, these figures would underestimate the problem, since contamination by medullated fibres will also result from crossbreeding Merino ewes with some traditional British breeds. The shift in farming enterprise by growers is attributable to high prices in the meat and live sheep trade. Data from Meat and Livestock Australia Ltd. (presented by Fleet *et al.* in2002[24]) highlights the change where in 1990, 15% of Merino ewes were mated to Non-Merino rams; but in 2002, this had increased to 44%.

2.1.4. Price Penalties for Contamination

As discussed in Sections 3.1.1 and 3.1.2, compensation for losses incurred through the delivery of a consignment contaminated with dark and/or medullated fibres results in claims from weaver to spinner to topmaker/buyer. If a Pre-Sale Test was available to determine all types and levels of contaminants in sale lots, the market would determine its own price penalties. In addition, if suitable trace-back procedures were in place, a grower may well find him or herself involved in a claim for compensation.

The new Pre-Sale Guidance Test for dark and/or medullated fibres has not, to date, been used routinely. Therefore, the market signals for contamination are not clear. In 1993, Pattinson and Hansen[25] calculated discounts of between 15% and 50% for pigmented fibres identified in greasy wool sale lots. They also reported a 15% penalty for heavily medullated fibre (floating kemp).

More recently[21], penalties across fibre diameters for the two seasons 2000/2001 and 2001/2002 averaged 11% for "Y1" (isolated), 29% for "Y2" (fibres readily evident) and 35% for "Y3" (clearly black or a mixture of black and white wool) levels of pigmentation. The authors found it more difficult to quantify the penalty for medullated fibre contamination as only four sale lots with a "P" qualifier were available for analysis. For these lots the discount averaged 67c/kg clean.

It is hoped that the implementation of a vendor declaration for dark and/or medullated fibre risk will eventually result in market signals that will particularly benefit the producers of white Merino wool of low contamination risk.

2.2. Remedying Dark and/or Medullated Fibre Contamination

Any remedy for the removal of dark fibre contamination along the wool pipeline must be cost-effective. Two devices have been invented to help overcome or minimise contamination problems. Since these devices are not always available, the manufacturer generally utilises traditional methods, such as dyeing or picking, to remedy the problem.

2.2.1. Sirosorter

The CSIRO Sirosorter device, developed in 1995[26,27] and commercially released in 1997, removes coloured faults from scoured and carbonised wool conveyed in an airstream. While it was developed principally for the wool industry, it has its greatest uptake in the cotton industry[28]. For niche market applications, such as the processing of high quality worsted products where the levels of contamination are minimal, pickers are employed to remove all forms of contamination from the scoured wool. In these circumstances, Sirosorter is an economic solution. However, it seems that its purchase and subsequent use for lower quality products is not cost-effective.

2.2.2. Siroclear

Siroclear was developed by CSIRO in the late 1980s for the identification and removal of coloured contaminants, including dark fibres, from undyed yarns[27,29]. Based on optical sensing technology, which can be adjusted to meet the requirements of the manufacturer, Siroclear is able to remove faults that would be normally mended out of a fabric. The device can be fitted on winding frames and can work in parallel with thick and thin place detectors.

Siroclear is now commercialised through the Swiss company Loepfe[30], who have incorporated it into their conventional clearers to allow continuous monitoring of not only contamination but also thick and thin places. While technically viable, the ultimate success of Siroclear in remedying dark fibre contamination is dependent on its sale to spinners. In addition, it may also be uneconomic to use Siroclear to remove high levels of contamination as it production may be slowed and wool wasted.

2.2.3. Corrective Dyeing

Unsuitable levels of dark and/or medullated fibre contamination for a particular end-use may be detected during mill inspections of tops, yarns or fabric. Assuming it is uneconomic or destructive to pick dark and/or medullated fibre contamination from a fabric, corrective dyeing may be undertaken by the processor[14]. Corrective dyeing may remedy a contamination problem; however, it is performed at additional cost.

In the case of dark fibre contamination, wool at any stage of processing could be dyed a darker shade to hide the faults. It is more difficult to remedy contamination by medullated fibres at the fabric stage. Corrective dyeing could take the form of a lighter shade or a mixture of shades if the medullated fibres are detected in the top, while fancy yarn dyes might be used to remedy problems at this stage.

2.2.4. Picking

Picking (see Figure 3), or the manual removal of faults from fabric, is common practice. However, excessive picking to remove contamination is not only expensive but it may also destroy the appearance of the fabric. Such losses will result in compensation claims.

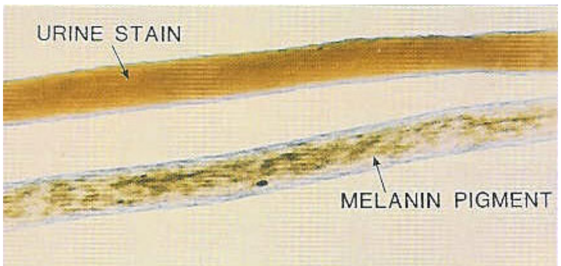
Figure 3 Picking fabric in a commercial mill

2.3. Measurement of Dark and/or Medullated Fibre Contaminants

2.3.1. Classification of Fibres

To the naked eye, dark brown fibres that are pigmented and urine-stained appear similar[5]. However, under microscopic examination (eg. 330x magnification), a urine-stained fibre is uniformly discoloured whereas in a pigmented fibre, the melanin granules, which vary in size, give a more uneven appearance (see Figure 4). This difference allows the source of dark fibre contamination to be determined during microscopic evaluation.

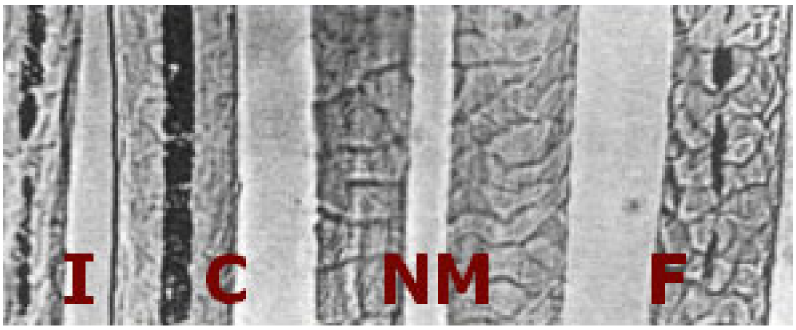
Figure 4 Sources of dark fibre contamination: urine-stain and pigmentation (Source: CSIRO[6])



Coarse fibres that posses a medulla (core of air-filled cells) are hairy and harsh in handle. The medulla may be continuous, interrupted, or fragmented (see Figure 5)[13]. In severe cases, most of the interior of the fibre is affected, and the fibre tends to become flattened, chalky-white and brittle - such fibres are generally known as "kemp". Note, for wool the term kemp is often used for shorter fibres that have been shed into the fleece.

Urine-stained, pigmented and medullated fibres are all quantified in terms of the number of each fibre type observed in a sample of fibres. The cleanliness of a combed sliver is measured according to IWTO Draft Test Method 24-01[31]; however, this method only counts the number of fibres in a known weight of sample, it does not differentiate between the fibre types.

Figure 5 Fibre medullation: interrupted (I), continuous (C), non-medullated (NM) and fragmented (F) (Source: SGS[13])



2.3.2. Reference Scale for the Colour of Dark Fibres

Both urine-stained and pigmented fibres vary in colour[5,32]. In response to the length of exposure to urine, fibres range in colour from pale yellow to nearly black. Pigmented fibres may differ in their depth of colour depending on the amount of melanin present and its dispersion.

This variation in colour is important, since in the assessment of faults in a fabric, fibres that are pale or light in colour (eg. yellow), may not be considered a commercial problem. That is, such pale fibres blend into the structure and coloration of the fabric. On the other hand, fibres that are brown to black in colour do create a commercial fault that needs to be remedied.

To help quantify the commercial occurrence of dark fibre contamination, Foulds *et al.*[33] developed a reference scale for the categorisation of the "colour" of the fibres. The scale has eight steps from white at 0 to black at 8 (see Figure 6). In between, the scale progressively darkens from yellow at 1 through to dark brown at 7. When applying the scale under commercial conditions, fibres with a reference value greater than 4 are considered as fault and are economically important[5].

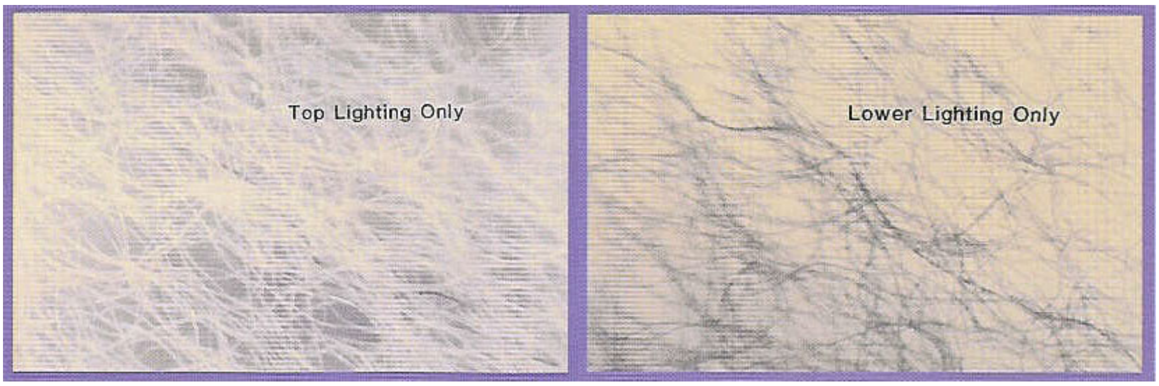
On the other hand, fibres that are urine-stained, pigmented or have stains such as canary stain, dag, pen stain, etc., whose reference value is often less than 4 can be ignored, as the fibre colour is too pale to be important to the manufacturer.

Figure 6 Reference scale for the colour dark fibres (Source: CSIRO[6])

2.3.3. CSIRO Dark Fibre Detector

In industry, wool is inspected to determine the quantity of dark fibres present; however, the procedures used for many years were far from robust. The use of a single light source above or below the fibres does not clearly reveal dark fibres (see Figure 7). In 1983, Foulds *et al.*[34] presented to the International Wool Textile Organisation (IWTO) an improved method for detecting dark fibres in raw wool or top. The method involves the use of balanced illumination whereby white fibres in a web will become nearly invisible when light is shone above and below it. At the same time, all the dark fibres are visible.

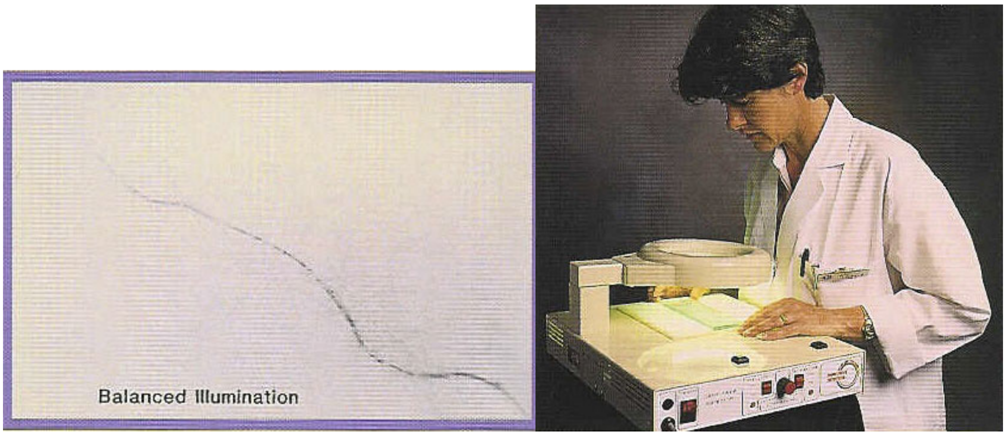
Figure 7 The illumination of a web using top lighting (left) and lower lighting (right) (Source: CSIRO[6])



Based on this lighting principle, the CSIRO Dark Fibre Detector was developed and commercialised (see Figure 8). The CSIRO Dark Fibre Detector (or any similar device) is used in conjunction with the IWTO Draft Test Method-13-01[20] for counting coloured fibres in tops. This method also utilises the CSIRO Colour Reference Scale in order to distinguish between fibres that are commercially significant and those that are not.

Use of the CSIRO Dark Fibre Detector involves the visual inspection of a homogenised sample of fibres usually prepared as a web. Given its design principles, it would be expected to be more reliable in the quantification of dark rather than medullated fibres. Clearly, the two major limitations with the Dark Fibre Detector are its use of visual assessment and lack of automation. That said; AWTA Ltd's Guidance Test is based on the Dark Fibre Detector (see Section 3.3.7).

Figure 8 Balanced illumination of the CSIRO Dark Fibre Detector (Source: CSIRO[6])



2.3.4. Optalyser

The Optalyser is an automatic instrument for counting and classifying cleanliness faults in tops such as straws, seeds, burrs, neps, slubs, and coloured fibres of different darkness levels[35,36]. It was developed by Centexbel of Belgium to overcome problems with visual inspection for coloured faults. The Optalyser, used according to IWTO TM-55-99[37], prepares a sample of top by drafting, with the web passed through the measurement area for optical inspection using electronic cameras. The results are reported as the number of each type of fault for each test specimen.

The development of the Optalyser was a step forward in terms of providing more objective and reproducible measurements of coloured faults, in accordance with commercial practice and IWTO recommendations. Unfortunately, the instrumentation is expensive; with only two instruments worldwide, thus its use by industry is extremely limited. In addition, it does not measure medullation.

2.3.5. Measurement of Medullation

Manual separation of fibres, microscopic counting, flotation and refraction techniques are all methods that have been used for the measurement of medullation[13]. All methods are time-consuming and require skill and experience, and as such, are costly and less than ideal. Recent attempts by WRONZ to produce automatic methods include the Medullameter and Near Infra Red Analyses (NIRA). The measurements use different interpretations for what constitutes medullation or "objectionable" fibres, and it thought that this partly explains their low uptake by industry.

2.3.6. Optical Fibre Diameter Analyser (OFDA 100)

The OFDA 100 was developed by BSE Electronics principally for the measurement of mean fibre diameter and its variability (see Figure 9)[38]. Since that time, the device has been adapted to facilitate the automatic determination of the medullated fibre content of wool and mohair based on opacity measurements[39]. Opacity is the ability of each fibre to transmit light. It is determined by the fibre's shape, internal structure, colour and surface quality. In fibres, medullation is a cause of opacity.

Despite its test method status, the OFDA 100 is not commonly used in Australia for the measurement of medullation. It has been suggested that the OFDA 100 over-estimates the medullation in Merino wools. As well, there are potential sampling issues associated with testing snippets. Until data proving the OFDA 100's ability to measure medullation in Merino wool is provided, it is unlikely that this instrument will gain favour as a test device. The OFDA 100 does not measure dark fibres.

Figure 9 The OFDA 100 (Source: BSE[38])

2.3.7. AWTA Ltd Dark and/or Medullated Fibre Testing Service

A guidance test, commercially available through AWTA Ltd, measures the dark and medullated fibre content of a scoured and Shirley analysed (carded) core sample[1,2]. The test is suited to clips where Merinos have been in contact with exotic breeds or their crosses, as this contamination is more randomly distributed through the fleece and bale; hence core sampling provides a representative sample. The test is not applicable to isolated urine-stain, pigmentation or medullation, where the faults are found in discrete locations in a fleece/bale), as a core sample is not representative.

The guidance test, which uses the CSIRO Dark Fibre Detector, is an adaptation of a test developed by South Australian Research and Development Institute. While the capital cost is low, the test is labour-intensive and thus costly. It is not a certified test, as the measurements do not meet the stringent standards required for IWTO Test Method status. To this end, the results are intended as a guide to producers who wish to manage contamination from exotic breeds, rather than as a definitive test.

2.3.8. Pre-Sale Testing of Greasy Wool

The measurement techniques referred to in Sections 3.3.1 to 3.3.7 are primarily used for the measurement of dark and medullated fibre faults in top. Technically, the same methods can be used to quantify dark and/or medullated fibre in greasy wool, although a clean, homogenised sample is required. As mentioned, the primary issue that negates the development of a Pre-Sale Test for greasy wool is sampling. Urine-stained and isolated pigmented or medullated fibres occur as discrete fibres, staples or tufts; therefore, core sampling does not produce a representative sample.

Research aimed at improving both the detection and measurement of pigmented and medullated fibres contaminants originating from contact between Merinos and exotic breeds or their crosses is underway. It is anticipated that it will be a few years before any development is commercially available as a Test Method. Work to address the sampling problems associated discrete clumps of urine-stain, pigmentation and medullation is not being undertaken, therefore, any new test will not quantify contamination of this type.

2.3.9. Top, Yarn and Fabric Testing

After conversion to top, contaminated fibres are randomly distributed. Therefore, the methods of detection and quantification presented in Section 3.3.1 to 3.3.7 are appropriate. However, improvements related to the provision of rapid, objective and repeatable measurements would be extremely beneficial to the wool industry.

Similarly, yarn and fabric testing remain labour-intensive, subjective techniques that would benefit from automation.

2.4. Sources of Contamination and Prevention Strategies

2.4.1. Urine-Stain of Merino Wool

Wool permanently stained through exposure to urine is well recognised[4]. Urine-stained fibres vary in colour from pale yellow to very dark brown; however, most commonly only brown fibres with a Colour Reference Value darker than Level 4 (see Section 3.3.2) are intolerable in knitted or woven fabric[5]. The variation in colour is largely attributable to the length of exposure of the wool to urine. It takes more than three months of exposure before the fibre is dark enough in colour to be detectable in fabric. Urine-stained fibres are uniformly discoloured, although fibre tips may be darker through longer exposure times. Note, dark fibre contamination does not often result from staining by water, ectoparasite infestation, dag or yolk, as the colours are not dark enough (Colour Reference Value less than Level 4).

A number of reports have summarised the factors contributing to the occurrence and magnitude of urine-stain contamination[3,5,40,41]. The primary determinant is the sex of the sheep in conjunction with flock management factors. They are considered below:

- **Ewes versus Wethers.** For wethers, urine-stain is concentrated in the belly wool around the pizzle. During shearing, the belly wool including urine-stain is removed first, and immediately separated from the fleece. For ewes, urine-stain is concentrated in the crutch region, which is removed in two steps during shearing: the left side is removed early and the right side towards the end. As crutch stain is not removed until the end of shearing, there is greater likelihood that it will contaminate the fleece. Thus, wool from ewes has a greater risk of being contaminated with urine-stain than that from wethers.

  In 1984, it was estimated that one third of Australian fleece lines would be adequate to meet the market for white/pastel end-uses. Co-incidentally, at this time, wethers made up approximately 30% of adult Merinos, so theoretically their fleece lines were sufficient to meet this demand. However, use of wether fleece lines only is not a practical solution, especially since the proportion of wethers making up the Australian flock has recently declined. Therefore, to boost the availability of wool of low urine-stain risk, it is necessary to consider wool from ewes.

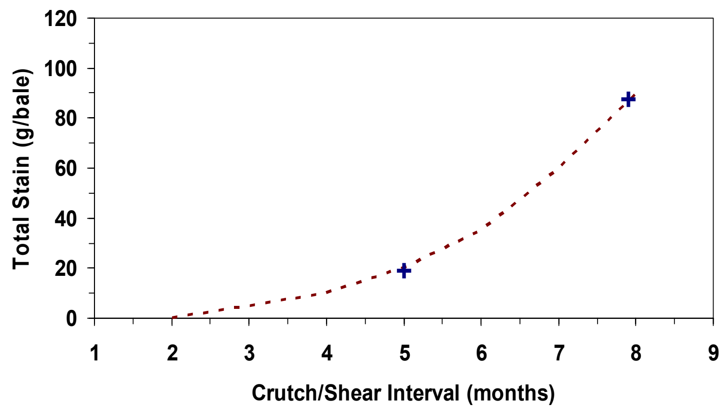
- **Ewes.** The factors that minimise the risk of urine-stain contamination of wool from Merino ewes are:
  - *Mulesing.* Mulesing, which removes excess wrinkles from the crutch region of sheep, is helpful in minimising urine-stain. For mulesed ewes, urine-stain was estimated to be one sixth of that for unmulesed ewes. However, no specific research has quantified the influence of mulesing on urine-stain contamination *per se*.

Crutching. The period between crutching and shearing affects the levels of contamination by urine-stain (see Appendix 5.1). Firstly, the total area of wool exposed to urine would expand as the time between shearing and crutching increased.

Secondly, as a rule of thumb, it was found that a crutch/shear interval of ≤3 months significantly reduced the risk of contamination by urine-stained fibre (see Figure 10). This is based on the principle that the depth of colour of a urine-stained fibre is mainly determined by the length of exposure to urine. When wool is exposed for less than 3 months, the colour produced is yellow or light brown (less than Level 4 on Colour Reference Scale).

- *Shearing.* Although a modified shearing technique, particularly applicable to ewes, where stain was removed at the start of shearing was trialled and considered useful, it did not gain favour with industry. This was possibly due to an increase in shearing time.

Figure 10 Increase in total urine-stain (g/bale) in response to crutch/shear interval (Source: Foulds, 1988[3])



- **Wethers.** The factors that influence the risk of urine-stain contamination of wool from Merino wethers are:
  - *Crutching.* For wethers, ringing is the critical action in crutching that removes wool (and urine-stain) from around the pizzle.
  - *Pizzle Dropping.* Some growers operate on wethers to lower the pizzle below the wool of the belly, thus reducing wetting by urine and minimising stain in belly wool.
- **Ewes and Wethers.** One major factor minimises the risk of urine-stain contamination of wool from both Merino ewes and wethers:
  - *Clip Preparation.* The compulsory Woolclasser Development Program facilitated by AWEX in 2001/2002 raised awareness and reinforced responsibilities of the woolclasser and grower in managing the risk of dark and/or medullated fibre contamination in the shearing shed. This program was considered highly successful; however, it is important that this knowledge be passed on to all members of the shearing team. All

staff, from the shed hand to the classer, must to be vigilant in the quest to identify and remove all dark fibre faults.

- *Minor Factors.* Additionally, a number of minor factors potentially influence the occurrence of urine-stain. These are as follows:
  - *Tail Docking.* Removal of the tail, preferably at the 3rd joint to allow the sheep to control it, reduces contact between urine and wool.
  - *Wool Cover.* Particularly for ewes, excessive wool down the rear legs increases the possibility of scorching by urine.
  - *Fleece Cohesion.* If a fleece holds together during shearing, it is easier to pick up and throw on a skirting table. Removal of stain is more effective for a cohesive fleece.
  - *Pasture.* The salts and solids within urine may be influenced by the types and availability of pasture and the physiology of the sheep.
  - *Rainfall.* Fluid intake of sheep may change in response to rain, which in turn may affect their urination behaviour.

2.4.2. Pigmentation of Merino Wool

As noted in Hawkesworth's textbook[4], pigmentation is a well-recognised facet of the wool fibre. Pigmentation is caused by a naturally occurring protein, melanin, which is produced as a granule by cells called melanocytes. These are usually found along the epidermal/dermal border, the outer root sheaths and in the bulbs of hair follicles. From these sites, melanin granules are passed into adjoining cells called keratinocytes, which subsequently develop into dead layers of skin or into wool or hair fibres. Due to the granular nature of melanin, the colour of a pigmented fibre is usually not uniform along its length. In white Merino sheep, melanocytes are often absent from wool follicles, but may be found in the epidermal/dermal border where their activity and distribution is usually low[42].

Since the early 1980s, significant research aimed at improving the understanding of fibre pigmentation in Merino sheep has been undertaken by staff of the South Australian Department of Agriculture, principally by M.R. Fleet, C.H.S. Dolling, J.E. Stafford and colleagues. The findings of this work were summarised by Fleet in 1985[42] and 2000[43] with the main points outlined below (see Appendix 5.2 for examples):

- **Genetic Pigmentation.** Pigmentation in fibres is generally of genetic origin (see Appendix 5.2.1); although it can be influenced by the environment (eg. the trace element copper is required for melanin to form). Black and brown sheep are a result of a recessive gene. They continue in white sheep flocks because there is no practical procedure to detect heterozygous rams. It is estimated that 6% of the Australian flock is heterozygous for the pigmentation gene; however, only a small percentage (~10%) of these sheep contain isolated pigmented fibres in their fleeces.
- **Piebald Sheep.** A piebald sheep has one or more patches of pigmentation and/or kemp in a white fleece. Its inheritance appears independent of the recessive black gene (described above), and is mostly likely the result of incomplete gene(s).

  It is important to cull black and piebald lambs as soon as practical, and where possible, cull their parents as they are carriers of the recessive gene. This will remove their potential influence on the gene pool and prevent the sheep-to-sheep fibre transfer from black to white sheep. This is important for piebald lambs, as their pigmented wool may be missed at shearing. Also, these sheep should be shorn after white sheep, with their wool kept separate from the white wool.

- **Coloured Birth Coats.** Coloured birth coat fibres on Merino lambs appear as tan patches, usually on the back of the neck (see Appendix 5.2.2). It is assumed that these tan fibres are shed soon after birth; however, it is recommended that lambs displaying extensive patches should be culled, or the male lambs castrated. Similarly, it is strongly recommended that lambs displaying dark halo hair and/or pigmentation on the legs or horn sites be culled, as these animals have an increased risk of developing isolated pigmented fibres later in life.

  Wool from such lambs or hoggets should be kept separate from white wool.

- **Isolated Pigmented Fibres***.* Inspection usually detects the occurrence of black, piebald and other congenital pigmentation (see Appendix 5.2.3). In contrast, isolated pigmented fibres occurring in white fleeces often escape detection. For this reason, isolated pigmented fibres are difficult to control; however, fortunately research has found that this form of pigmentation often decreases with age[44].

  If isolated pigmented spots or fibres are identified, the sheep should be culled and their wool kept separate from white wool.

- **Non-Wool Pigmentation.** Non-wool pigmentation is that found on the nose/lips, eyelashes, inside the mouth, legs, hooves and horns (see Appendix 5.2.4 to 5.2.6). It generally increases with age. The strongest indicator of isolated pigmented fibres is pigmented leg hair, followed by horn sites, eyelashes, skin, hooves and lips. Most forms of non-wool pigmentation are correlated; hence, there are benefits to be gained from culling sheep displaying any type.

  Inspection at shearing and crutching is recommended. Wool from sheep with non-wool pigmentation should be kept separate from white wool.

- **Non-Congenital Pigmentation (Age Spots).** Adult Merino sheep develop pigmented skin spots with age called non-congenital pigmented spots (see Appendix 5.2.7). These spots often contain a small number of pigmented fibres. However, this source of dark fibre contamination is considered minor as sheep need to be quite old (>8.5 years) before a significant number of spots develop, and except in pastoral regions, most sheep are culled before they reach this age.

  It is preferable that the wool from sheep older than 6 years be kept separate from other lines. If this is not possible, shearers should be asked to identify individual sheep with black or grey skin spots that usually occur on the back-line and sides.

In general, due to traditional selection against all types of pigmentation, its occurrence in Australian Merinos is considered low. A defining characteristic of Merino pigmentation is that it may occur as discrete, isolated fibres or staples, which causes problems for sampling and detection. Similar to urine-stain, any new measurement will not result in a Pre-Sale Test suitable for isolated pigmentation found in Merinos.

2.4.3. Pigmentation and Medullation of Non-Merino Wool

Hatcher 2002[9], summarised the work of Ryder and Stephenson[45], Fraser and Short[46], and Lang[47], who studied the evolution of the domestic sheep from the wild sheep.

The coat of the wild sheep typically had two layers, a coarse outer coat and a fine woolly undercoat that moulted in spring. Also, for camouflage purposes, it was black, brown grey and/or white in colour. To a greater or lesser extent, sheep breeds today have some of the characteristics of the wild sheep, depending on their habitats and the selective breeding imposed by man. The Merino is considered the most highly developed breed as it grows wool continuously, with both pigmentation and hair generally not tolerated.

Today, four major fleeces types are recognised. They are: hair, long wool, double coated and the Merino. The fleece types are distinguished by the size and shape of the follicle, the number and arrangement of follicle groups, the type of fibre grown by the follicles and the characteristics of those fibres (see Appendix 5.3.1[48]). Both primary and secondary follicles are found in all fleece types, with the ratio between them, the secondary to primary (S/P) follicle ratio, a primary determinant of the types (see Appendix 5.3.2 for a comparison of breeds[48]).

For example, the more primitive types, such as hair and double coated, have low S/P ratios, low follicle density and a large size difference between the primary and secondary follicles. Fibre shedding is also a characteristic of primitive double coateds, with autumn and spring shedding of primary fibres and spring shedding of secondary fibres. Note, the extent of shedding under Australian conditions has not been studied. This is in contrast to the Merino, which has a high S/P ratio combined with high follicle density and little difference in size between the primary and secondary fibres. The Merino fleece does not shed except in extreme circumstances such as nutritional or health-related stress.

The fleece types of non-Merino breeds common in Australia are summarised[9,22,45,49]:

- **Hair Sheep.** Hair sheep are most similar to the wild sheep. Typically, they have a short kempy outer-coat with an undercoat of fine wool fibres. They have a low S/P ratio, with the kemp generally growing in the large primary follicles and the wool in the smaller secondary follicles. Their colours range from black to brown to white.
    - *Damara.* The Damara, recently imported from South Africa, is a highly fertile fat-tail sheep that is used primarily for meat (see Appendix 5.4.1). It is a typical hair sheep with an outer coat of kemp and an inner coat of wool. The fleece, which sheds, may be black, tan, brown or white-spotted. The coarse fibre is highly medullated. Around half the Damara and Damara cross sheep are found in WA, with smaller numbers located in SA, NSW and QLD (note, Aust. total approx. 234,300 sheep in 2001).
    - *Dorper.* The Dorper was developed as a mutton breed in South Africa in the 1930s (see Appendix 5.4.2). It typically has a black head and a white body. The fleece, which sheds if not shorn, contains floating kemp that is usually medullated. Imported to Australia in 1996, two thirds of Dorper and Dorper cross sheep are found in WA, with approximately one third in NSW (note, Aust. total approx. 16,500 sheep in 2001).
- **Double Coated Sheep.** The follicle patterns and fibres types of double coateds are similar to wild sheep. The primary follicles usually produce long hairs or heterotype fibres that grow for longer periods prior to shedding.
    - *Awassi.* The Awassi is a fat-tailed sheep originating in the Middle East (see Appendix 5.4.3). It has a carpet wool coat that contains hair, wool, heterotype and kemp in approximate proportions of 45%, 39%, 10% and 6%, respectively. The fleece of the Awassi ranges from brown to white,

with darker colours appearing on the head and legs. Awassi crosses are located in WA (note, Aust. total approx. 400,000 sheep in 2001).

- *Karakul*. The Karakul is a fat-tailed sheep sourced from the Middle East in the 1980s (see Appendix 5.4.4). It is a carpet wool type comprising a long lustrous outer coat, which is often black, although red, brown and white fleeces have been observed. Karakul crosses are found in WA (note, Aust. total approx. 260,000 sheep in 2001).

- **British Breeds.** The coat of traditional British breeds varies considerably, ranging from short, fine Downs wool to the longer, coarser, more lustrous fleeces of Long Wool or Mountain sheep. Pigmentation is common for all breeds, particularly on the points of the sheep, with medullation and shedding often characteristic of the Long Wool and Mountain types.
  - *Long Wool Sheep.* Long Wool British breeds commonly found in Australia include the Leister, Lincoln, Border Leister, Romney and Cheviot.
  - *Short Wool Sheep.* Short Wool or Downs breeds, originating in Britain include Southdown, Wiltshire Horn, Dorset Horn, Suffolk and Dorset Down.

    The Wiltshire Horn (see Appendix 5.4.5) is unusual as it sheds its wool in spring, with its hairy undercoat remaining over summer[50]. As such, the Wiltshire Horn is currently given an AWEX Risk Rating of 5[11].
  - *Mountain or Highland Sheep.* Mountain or Highland sheep are not common in Australia but include the Scottish Blackface, Welsh Mountain, Exmoor, Dartmoor and Shetland. Their fleeces contain a large proportion of hairy fibres, with kemps common.
- **European Breeds.** Though rare in Australia, breeds such as the Texel and the Finn have been imported into Australia for the quality of their meat, combined with high fertility. They are crossed with Merinos for fat lamb production. Like British Breeds, European sheep potentially have pigmented and medullated fibres, with their wool not suited to the white and pastel trade.
- **Carpet Wool Breeds.** Carpet wool breeds such the Drysdale and Tukidale are not common in Australia. Their wool is highly medullated; however, it is typically sold to the carpet wool industry.
- **Crossbreds.** Crossbred is the generic name commonly applied to sheep whose parentage is mixed, often Merino with another breed. To some extent, wool from Crossbreds is a blend of the characteristics of both breeds.

  Specific breeding programs, directed towards the production of dual-purpose sheep, have led to the development of new breeds such as the Corriedale and Polwarth. Similarly, programs involving British breeds have resulted in new meat breeds such as the White Suffolk and Coopworth. Due to their genetic background, their wool has a high risk of dark and/or medullated fibres.
- **Merino.** The defining characteristic of the Merino is its well-developed fleece type with high follicle density, a high S/P ratio with little difference in the size of the primary and secondary follicles. Medullation is unusual in the Merino, only occurring rarely in very coarse fibres. Thus, similar to pigmentation, medullated fibre contamination is not considered a major problem in wool of Merino origin. Specific sub-types of the Merino, including the Australian Superfine, Dohne and South African Meat Merino (SAMM), all have low pigmented and medullated fibre risk.

The transfer of pigmented and/or medullated fibres from fleece to fleece presents a new cause for concern regarding contamination. Hatcher[9] and Fleet[49], in their reviews of the introduction of exotic meat production breeds into Australia, cite numerous studies verifying that fibre transfer may result from direct contact between sheep, be they the same or different breeds. This transfer of pigmented and/or medullated fibres occurs from non-wool growing areas (such as the face, legs and belly) to wool growing areas as well as between wool-growing areas.

Obviously, the risk of fleece-to-fleece transfer is higher if the period of contact is prolonged or the contact is close (eg. in yards or small paddocks). To minimise the contamination risk, it is recommended that Merino ewes mated to non-Merino breeds should not be shorn for at least two months post-mating. This practice may be useful; however, it should be remembered that the Merino ewe will later have extended contact with its crossbred lamb.

In crossbreeding Merino ewes with non-Merino rams, the type and number of contaminant fibres transferred to the ewes is largely dependent on the breed of ram, the length of mating, the size of the mating paddock and the ratio of rams to ewes. Note, there is no contact between breeds if artificial insemination is used to mate the ewes; however, this is often not practical (eg. for reasons of cost).

It is, of course, necessary that Merino ewes raise their crossbred lambs. Extensive fibre transfer between the lamb and its mother has been observed[9], with the level of contamination largely determined by breed differences in the pigmentation and medullation of the lamb's fleece and the extent and timing of fibre shedding. Additional influences include the time from birth to weaning, the size of the lambing paddock, the stocking rate, the number of lambs raised, the timing of shearing, the length of wool of all sheep, vegetable matter content of the fleece, etc.

The AWEX ID Appraisal Guidelines[12], which apply to wool sold at auction, recognises that non-Merino breeds vary in their level of pigmented and/or medullated fibres. If they are appropriately described, as required, buyers can avoid the purchase of wools from non-Merino breeds or their crosses. Non-Merino wool should be kept separate from Merino wool. In addition, wool from non-Merino breeds or Merinos run with or giving birth to non-Merino breeds can be clearly identified using Crossbred (X), Downs (D) and Carpet (T) breed identifiers and/or the qualifiers for Black and Grey Wool (Y) or Kemp (P).

AWEX has developed a Risk Rating based on the degree of pigmentation and medullation and whether the breed sheds fibres. The Merino and Australian Superfine are given the lowest Risk Rating of 1. In contrast, five breeds were allocated the highest Risk Rating of 5 (they shed pigmented and/or medullated fibres). For the purposes of this report, these breeds are termed exotics. The breeds are:

- **Breeds with an AWEX Risk Rating of 5:**
    - **Awassi:** Pigmented heads and necks, fat tailed breed, carpet wool sheep consisting of an outer hairy coat and inner wool coat.
    - **Damara:** Shedding hair coat, carpet wool.
    - **Dorper:** Pigmented head and necks, short shedding wool, fleece containing kemp.
    - **Karakul:** Pigmented body, carpet wool fleece, fat-tailed breed.
    - **Wiltshire:** White open face and points, rams and ewes horned, horn coloured hooves. Sheds fleece.

The AWEX Code of Practice[11] stipulates that if different breeds or crosses are being shorn in the same shed, preventative measures should be used to minimise the risk of contamination. These measures relate to the order of shearing different flocks and clip preparation.

- **Order of Shearing.** To be from least to most potential for contamination:
  - White wool sheep at low risk of pigmented or heavily medullated fibres (eg. Merino).
  - White wool sheep joined to pigmented, partly pigmented or heavily medullated rams.
  - White wool sheep that have reared, or been run together with, pigmented, partly pigmented or heavily medullated lambs/sheep.
  - White wool sheep marked as culls because of pigmented or medullated fibres.
  - Sheep with obviously pigmented or medullated wool.
- **Clip Preparation:**
  - In addition, the wool from pigmented or medullated sheep is to be dedicated to an enclosed area to prevent trafficable and wind assisted movement of the potential contaminant.
  - The shed must be thoroughly cleaned between the shearing of that wool containing kemp (eg. Carpet wool sheep) and pigmented wool sheep and the shearing of white wool sheep.

2.5. CSIRO Dark Fibre Risk Scheme

It is clear from the literature that methods to clearly identify contamination by dark and/or medullated fibres prior to sale are not likely in the foreseeable future (for discrete contaminants such as urine-stain and isolated pigmentation or medullation) or are a few years from commercialisation (for pigmentation and medullation resulting from contact with exotics). Therefore, it is essential that other mechanisms be investigated to provide:

- growers with the opportunity to promote their clip(s) as having a low risk of contamination, and
- buyers and/or topmakers with objective information on the potential risk of contamination of a sale lot by dark and/or medullated fibres.

With respect to the problem of dark fibre contamination, a predictive method of determining the risk of dark fibre contamination was proposed by Roger Foulds of CSIRO Division of Wool Technology in 1988[3].

This scheme utilised knowledge of the factors that influence the risk of dark fibre contamination of urine-stain or isolated pigmentation origin. These factors, which were discussed primarily in Section 3.4.1, were determined through extensive research conducted during the 1980s. The scheme was based on information that could be provided by the grower at the time of shearing. Although the concept was never implemented commercially, it was positively received by the wool industry.

The principles of a decision scheme to predict dark fibre risk along with the factors influencing the calculation of the risk were presented in Fould's original paper[3]. Research to validate the underlying assumptions of the DFRS was subsequently conducted and reported to industry[19,51,52]. These developments are reviewed in the ensuing sections.

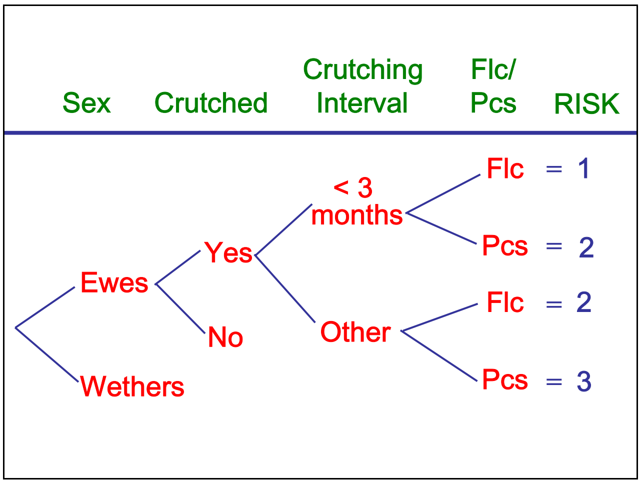
2.5.1. Principles of Dark Fibre Risk Scheme

The underlying procedures and statistical basis for a assessing the dark fibre concentration in a top were presented by Foulds in 1986[53], with advanced details provided by Turner and Foulds in 1987[54]. On a practical level, these assumptions were then incorporated into what is now known as the Dark Fibre Risk Scheme (DFRS) or Dark Fibre Risk Tree (DFRT). It is important to note that in developing the DFRS, the intention was to produce an objective risk level since an objective test for isolated pigmentation and urine stain is not feasible.

A decision tree involves a series of questions with a number of potential answers (ie. branch points). Follow-on questions branch in response to the resultant answers. This process is continued until all relevant factors have been considered, with the "Risk" then calculated.

It was intended that the DFRS be applied to individual sale lots, with the questions at each branch point designed to elicit an objective response. Figure 11 depicts successive questions required for the calculation of a dark fibre "Risk". These relate to the sex of the sheep, crutching, the crutch/shear interval and the shed line. A dark fibre "Risk" is calculated once all questions have been answered. Note, Figure 11 shows one branch and does not demonstrate the full complexity of the DFRT.

Figure 11 Section of original dark fibre risk tree (Source: Foulds, 1988[3])



2.5.2. Factors influencing Prediction of Dark Fibre Risk

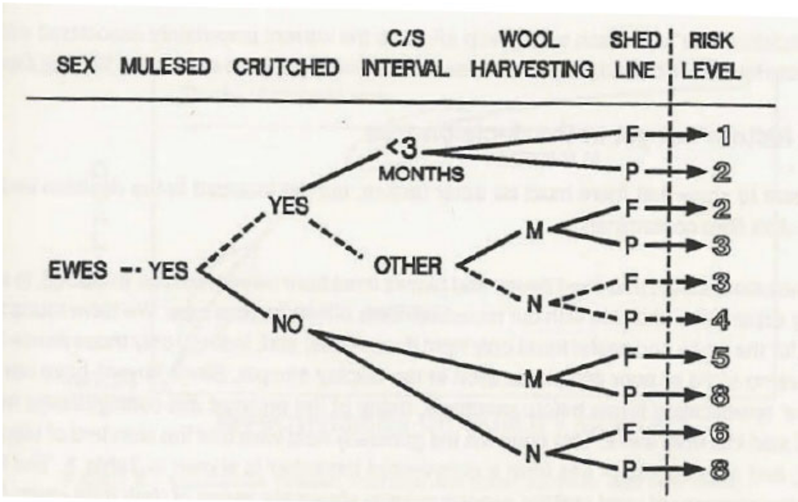
Section 3.4 detailed sources of dark fibre contamination and potential risk minimisation/prevention strategies. This knowledge was used to formulate questions for the DFRS (see Table 3, next page), with care taken to ensure that all questions could be answered with objective information obtained at shearing[3].

The DFRS assumes a benchmark level of 100 df/kg (Section 3.1.3). That is, if dark fibre levels are below this level, the wool is deemed suitable for the white and pastel trade. It was originally anticipated that eight (8) Risk Levels would be derived from DFRS. In these circumstances, Risk Levels 1 and 2 would be below this benchmark; Level 3 would be just above and Levels 4 to 8 progressively higher. Utilising some of the factors listed in Table 3, Figure 12 demonstrates how the decision tree and the Risk Scale might work in the case of urine-stain for ewes.

Table 3 Factors in the original Dark Fibre Risk Scheme[3], the type of dark fibre contamination and options for each branch point

Factor	Type	Branch Option 1	Branch Option 2
Breed	Pigment	Merino	XBred & CBack
Age	Pigment	Adult Sheep	Lms, Wnr, Hgt
Age	Pigment	<6 years old	>6 years old
Sex	Urine-Stain	Wether	Ewe
Mulesing	Urine-Stain	Yes	No
Crutching	Urine-Stain	Yes	No
Crutch/Shear Interval	Urine-Stain	≤3 months	>3 months
Harvesting	Urine-Stain	Modified Shearing	Normal Shearing
Shed Line	Urine Stain	Fleece	Pieces

Figure 12 A section of a Dark Fibre Risk Tree showing the branches used for urine-stain control in ewes (Source: Foulds 1988[3])



2.5.3. Validation of Dark Fibre Risk Scheme

It should be noted that it is rare for a top to have zero dark fibres. Australian Merino wool generally has a background level of contamination of <100 df/kg. This is present because, despite careful breeding, isolated pigmented fibres may occur. Equally, the best stain-prevention procedures may not eliminate all urine-stained fibres. For Merinos, contamination above this background level is usually caused by urine-stain.

Validation compares the "Risk" predicted using the DFRS with actual dark fibre test results produced for tops of known origin. Validation trials were conducted using firstly, sale lots individually selected to evaluate the influence of specific factors on dark fibre contamination and secondly, commercial consignments where the component sale lots were known[19,51,52]. For these studies, dark fibres were colour graded as medium or dark according to IWTO DTM-13-01[20], as these criteria are equivalent to commercial fault levels. The results of these validation trials follow:

- **Breed**. Little information is available on the dark fibre risk presented by non-Merino breeds. Of 101 individual sale lots processed to top, two were Corriedale, one fleece and one pieces. They contained a total dark fibre count of 747 and 1451 df/kg, respectively. These results were consistent with an evaluation of four commercial Crossbred consignments, two fleece wool and two lambs wool. The mean dark fibre count for the four consignments was 2115 df/kg, with the majority of the dark fibres being pigmented.

The results of these trials, summarised in Table 4, reinforces the commercial practice of avoiding wool from non-Merino breeds if a top suitable for the white and pastel trade is required. The data also highlights the high levels of pigmentation found in young sheep.

Table 4 Dark fibre counts (df/kg) for sale lots and consignments (Source: Burbidge *et al.* 1993[19] and Burbidge *et al*.1991[51])

Source	Breed/Category	Stain df/kg	Pigment df/kg	Total DF df/kg
Sale Lot 1	Corriedale FLC	651	96	747
Sale Lot 2	Corriedale PCS	1088	363	1451
Consignment 1	XB FLC*	19	10	29
Consignment 2	XB FLC*	33	144	177
Consignment 3	XB LMS*	306	3265	3571
Consignment 4	XB LMS*	426	4255	4861

* Actual breed not known.

- **Age (Adults).** Studies have shown an increased incidence of pigmented spots with age (non-congenital pigmentation), mainly due to exposure of skin to the sun. It was originally thought that wool from sheep >5 years old may have excessive age-related pigmentation. However, inspection of six sale lots showed an average of only 23 df/kg (maximum 39 df/kg); with this level similar to background pigmentation and much lower than the critical 100 df/kg.

  Recent studies[44], have found that age-related pigmentation increases most dramatically after a sheep reaches 6 years of age. However, they need to be quite old (>8.5 years) before a significant number of spots develop. Except in pastoral areas, most sheep culled before they reach this age.

- **Age (Young Sheep).** Congenital pigmentation is the primary cause of dark fibre contamination in young sheep; however, it usually diminishes as they become adults. Sale lots from young sheep of known ages were processed to determine the trends in pigmentation. The data were grouped into three age groups (≤1, 1-2 and ≥2 years) and two wool categories (fleece and pieces), with the results presented in Table 5.

  Note, the values in Table 5 represent pigmented fibres only, not the total dark fibre contamination. Any urine-stained fibres would, of course, increase the total dark fibre contamination of wool from these young sheep.

Table 5 Relationship between mean pigment levels (df/kg) and age, n=161 lots (Source: Burbidge and McInnes 1994[52])

Category	≤1 yr (df/kg)	1-2 yrs (df/kg)	≥2 yrs (df/kg)
FLC	204	44	23
PCS	251	91	57

It is clear that wool from sheep ≤1 year old present a much higher pigmented fibre risk than sheep 1-2 and ≥2 years in age. The higher counts for the pieces may be due to higher levels occurring on a sheep's points.

The trend for pigmentation to decrease with age was confirmed by the results from commercial consignments of Australian wool (see Table 6). In comparison to fleece or pieces only, consignments containing lambs wool had very high levels of pigmented fibres. While the pigmentation counts were lower for the consignments containing weaner wool, it appears that the more weaner wool present, the greater the chance that 100 df/kg limit will be exceeded.

Table 6 Mean dark fibre content (df/kg) of Australian consignments for different wool categories, highest to lowest percentage (Source: Burbidge *et al.* 1993[19])

Category	No. Consignments	Stain (df/kg)	Pigment (df/kg)	Total DF (df/kg)
FLC	**34**	53	37	90
PCS	**13**	247	65	312
FLC/PCS/LMS	**2**	146	731	877
PCS/LMS/BLS	**2**	1212	597	1809
FLC/WNR	**13**	69	25	94
WNR/FLC	**3**	126	126	252

- **Sex.** The relative levels of dark fibre contamination for Merino ewes and wethers were established using data where the underlying sheep husbandry practices were the same. These practices were mulesing with a crutch/shear interval greater than 3 months. Table 7 presents sale lot data that compares the stain and pigment levels for the fleece and piece lines of wool from ewes and wethers. The number of sale lots in this trial was not reported.

Table 7 Mean dark fibre content (df/kg) of ewe and wether sale lots for different wool categories (Source: Burbidge and McInnes 1994[52])

Sex	Category	Stain (df/kg)	Pigment (df/kg)	Total DF (df/kg)
Wethers	**FLC**	43	29	72
	PCS	115	20	135
Ewes	**FLC**	55	17	72
	PCS	267	106	373

The data shows that ewes have higher levels of urine-stained fibres, particularly in the piece lines. The lower levels of contamination for wethers is because the pizzle stain is removed with the belly wool. Pigmentation levels are similar for ewe and wether fleece lines. Higher levels of pigmentation were observed for ewe piece lines; however, the reason for this is not known.

- **Mulesing.** Foulds[3] reported that at least for wrinkly sheep, mulesing reduced urine stain by about one sixth compared with unmulesed ewes. However, no specific trial data was available to validate the influence of mulesing on dark fibre levels, particularly urine-stain.

- **Crutching and Crutch/Shear Interval**. Un-crutched sheep have the potential to produce high levels of stain. A supplementary consideration is the crutch/shear interval, where fibres stained by urine for less than 3 months would not be sufficiently dark to cause a visible fault. Batches sourced to compare the stain levels related to crutching (see Table 8) indicated a dramatic rise in urine-stained fibres as sheep are crutched ≤3 months before shearing, crutched >3 months before shearing, or not crutched at all.

Table 8 Urine-stain content (df/kg) of fleece and piece sale lots with crutch/shear interval ≤3 months or >3 months or not crutched (Source: Burbidge and McInnes 1994[52])

Category	≤ 3 months (df/kg)	> 3 months (df/kg)	Not Crutched (df/kg)
FLC	15	70	302
PCS	11	251	2366

- **Modified Shearing.** Modified shearing was initially included as a factor influencing the risk of dark fibre contamination. Preliminary data from two sale lots prepared using this technique revealed low levels of urine-stain. However, as modified shearing did not gain popularity amongst shearers and/or growers, it is not required in the risk scheme.
- **Shed Line or Wool Category.** Data presented in Tables 2, 4, 5, 6, 7 and 8 indicate a significantly higher level of urine stain in piece lines compared with fleece lines. To a lesser extent, the same trend was observed between the pigmentation levels for fleece and piece lines. Table 9 (a reproduction of Table 2), shows the contamination levels of 111 commercial consignments comprising both individual wool categories and blends. Wool categories are reported in order of highest to lowest contribution to the blend.

In order of increasing levels of contamination by urine-stain, wool categories are ranked as follows. FLC, PCS, BLS and STN. Similarly, in order of increasing levels of contamination by pigmentation, the wool categories are ranked: FLC, PCS, WNR, LMS and XB.

To summarise, when CSIRO's dark fibre research program ceased in the mid-1990s, the factors that validation trials determined were important in terms of estimating the dark fibre risk were: breed, age, sex, crutching, crutch/shear interval and shed line.

Table 9 Relative incidence (df/kg) of urine-stained & pigmented fibres in Australian consignments (Source: Burbidge *et al.* 1993[19])

Wool Category	No. Cons.	Number dark fibres per kilogram (df/kg)		
		Stain	Pigment	Total Stn+Pig
Flc	34	53	37	90
Pcs	12	247	65	312
Flc/Pcs	19	48	36	84
Flc/Pcs/Lms	2	146	731	877
Pcs/Bls	13	1,051	120	1,171
Pcs/Lms/Bls	2	1,212	597	1819
Bls/Stn/Pcs	1	58,461	0	58,461
Flc/Wnr	13	69	25	94
Wnr/Flc	3	126	126	252
XB	4	196	1,919	2,115
Flc/Mx	8	32	24	56

3.5.4 Interpretation of Dark Fibre Risk Levels

After reviewing the sale lot data, CSIRO revised the number of risk levels in the scheme[52]. This decision was made because the original scheme over-estimated the number of dark fibres in fleece and piece lines, with the maximum for any sale lot in the trials being approximately 1000 df/kg. It was confirmed that sale lots with Risk Levels between 5 and 8 had a very high probability of the dark fibre count exceeding 100 per kg. Although the level of stain found in belly wool commonly exceeds this value (eg. >3500 - 29,000 df/kg have been reported), belly wool is generally avoided in the white and pastel trade.

In 1994[52], a five level scale was proposed. Based on data from 161 Merino sale lots, the probability that a sale lot would be under the 100 df/kg benchmark was calculated for each Risk Level (see Table 10).

Table 10 For each Risk Level, the mean df/kg and percentage of lots with ≤100 df/kg (Source: Burbidge and McInnes, 1994[52])

Risk Level	No. Lots	Mean df/kg	% Sale Lots with ≤100 df/kg	Probability	95% CL
1	5	43	100	1.00	0.54
2	35	72	77	0.77	0.62
3	56	112	68	0.68	0.56
4	35	254	43	0.43	0.28
5	30	802	20	0.20	0.09

The 95% Confidence Limit (CL) value means that a lot chosen at random from within a Risk Level will have a certain probability of its dark fibre content being <100 df/kg. For example, a lot chosen from Risk Level 2 has a 62% chance of having a dark fibre count <100/kg, whereas a sale lot chosen at random from Risk Level 5 has a very low chance (9%) of having a dark fibre count <100/kg.

The interpretation of "Risk" described above is complex and would require a considerable explanation and trialling prior to its uptake by industry. Originally, it was thought that each Risk Level derived using the DRFS would equate to a particular dark fibre value (or range). The application of estimated values to each Risk Level would be simple to explain, however, the ramifications of doing so needs to be carefully considered.

3.5.5 Calculation of Risk Levels

Reports prepared by CSIRO on the DFRS do not publish the method for calculating Risk Levels[3,19,51,52]. It is likely that this detailed information is located in CSIRO archives. However, the research papers provide examples of the derivation of Risk Levels based on various wool types, along with breeding, husbandry and harvesting practices. Information has been extracted from these examples to derive Risk Levels (1 - 5) for a range of factors. For the five Risk Levels, an attempt has been made to equate each Risk Level to a range in dark fibre counts (see Table 11).

Table 11 **Examples of Dark Fibre Risk Levels estimated using information in CSIRO reports (Source: Foulds 1988[3], Burbidge *et al.* 1993[18], Burbidge *et al.* 1991[50] and Burbidge and McInnes 1994[51])**

Breed	Category/Desc.	Age	Crutched	Crut/Shear	Sex	Shed Line	Risk
Non-Merino	Non-Merino Breeds & Crosses						5
Merino	Not FLC/PCS/LMS						5
Merino	Y suffix						5
Merino		All	No		Ewes and/or Wethers	PCS	5
Merino		All	No		Ewes and/or Wethers	FLC	4
Merino		>8 yrs	Yes		Ewes and/or Wethers	FLC/PCS	5
Merino		≤1 yr	Yes		Ewes and/or Wethers	FLC/PCS	4
Merino		1-2 yrs	Yes		Ewes and/or Wethers	FLC/PCS	3
Merino		2-8 yrs	Yes	>3 mths	Ewes	PCS	4
Merino		2-8 yrs	Yes	>3 mths	Wethers	PCS	3
Merino		2-8 yrs	Yes	>3 mths	Ewes and/or Wethers	FLC	2
Merino		2-8 yrs	Yes	≤3 mths	Ewes and/or Wethers	PCS	2
Merino		2-8 yrs	Yes	≤3 mths	Ewes and/or Wethers	FLC	1

Approx. Dark Fibre Counts for Risk Levels:

1=<50 df/kg, **2=**50-100 dk/kg, **3=**100-200 df/kg, **4=**200-500 df/kg, **5=**>500 df/kg

Legend (AWEX ID, where applicable**):**

BREED - *Non-Merino:* Exotic, British, European, X-Bred (X), Downs (D), Carpet (T) ***Merino:*** Superfine (AS), Dohne, SAMM

WOOL CATEGORY - *SHED LINE*: FLC (F) or PCS (P) ***Not FLC, PCS or LMS*:** BLS (B), CRT (C), LKS (Z), STN (S)

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5. APPENDICES

Appendix 5.1 (a) Urine-stained wool on the crutch of a ewe and (b) Minimisation of urine-stain of crutching 3 months prior to shearing (Source: Fleet, 2000[42])

(a) (b)

Appendix 5.2 Merino Pigmentation (Source Fleet, 2000[42])

Appendix 5.2.1 Twins, one black and one white from carrier parents

Appendix 5.2.2 Lamb with tan halo hairs on back of neck

Appendix 5.2.3 White lamb showing random black spot

Appendix 5.2.4 Pigmented leg hairs and streaks on hooves

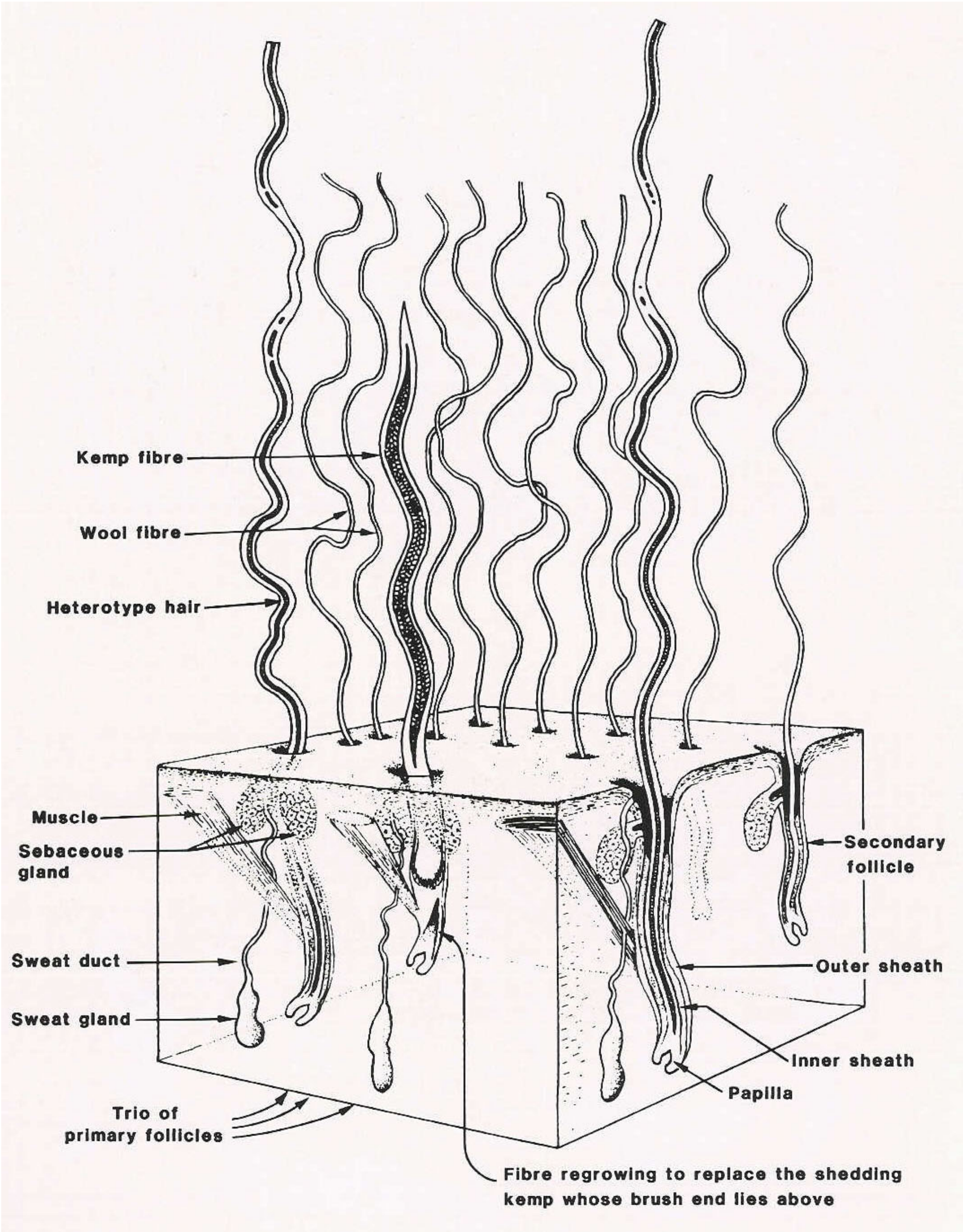
Appendix 5.2.5 Pigmented hairs on horn sites and face

Appendix 5.2.6 Pigmented hairs on eyelashes and tips of ears

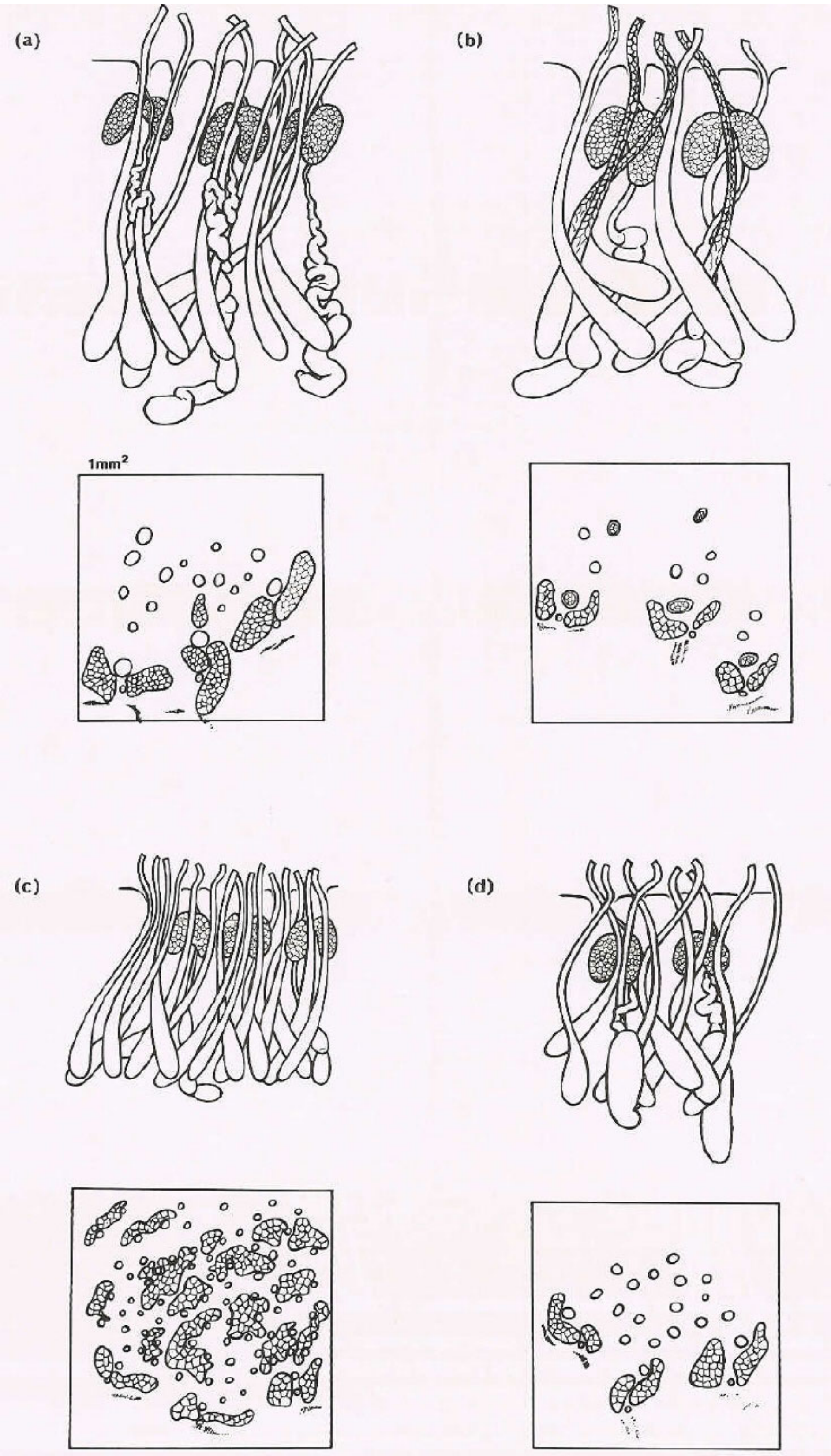
Appendix 5.2.7 Non-congenital pigmentation spots from old age

Appendix 5.3 **Stylised diagrams of skin, follicles and fibres (Source: Maddocks and Jackson, 1988[47])**

Appendix 5.3.1 **Idealised wool follicle group showing three types of fibre and two types of follicle in the skin**



Appendix 5.3.2 The skin structure of four breeds of sheep. (a) Long wool type - Lincoln, (b) Double coated type - Wiltshire Horn (c) Fine Merino and (d) Downs Wool - Dorset Horn



Appendix 5.4 Shedding sheep breeds commonly found in Australia (Source: Douglas 2001[21]; Fleet 2000[42]; Wiltshire Horn Assoc. 2003[49])

Appendix 5.4.1 Damara ewe and Damara crossbred lambs with Merino ewes

Appendix 5.4.2 Dorper ram and first cross Dorper x Merino lambs and comeback Dorper lamb (centre)

Appendix 5.4.3 Awassi ram and Awassi Merino cross sheep

Appendix 5.4.4 Karakul ram

Appendix 5.4.5 Wiltshire Horn ram and Wiltshire Horn ewes