FIBRE MEDULLATION, MICRON, MARKETING AND MANAGEMENT

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SUMMARY
There are vast differences between the 'exotic' sheep breeds currently run in Australia with respect to their fleece structure, fibre type composition and characteristics such as fleece shedding, pigmentation and medullation. This leads to different end uses for the fleeces from these breeds and different potential to impact upon the Australian wool clip. A greater understanding of the biology of these exotic breeds and the consequences on the fleece of crossing with the Merino is required in order to develop improved management strategies to minimise the risk of pigmented and medullated fibres contaminating Merino fleeces. Furthermore an investigation into the persistence of various animal contaminant fibres in both the worsted and woollen processing systems and the commercial development of a novel pre-sale test for quantifying dark fibres in sale lots are important. Comprehensive work in these two areas will provide a clear indication to the processing industry of the incidence and relative importance of animal fibre contaminants in the Australian wool clip.

Keywords: fleece structure, fibre types, pigmentation, medullation, fibre contamination

INTRODUCTION
There are four main types of wild sheep from which domestic sheep have been derived (Ryder and Stephenson 1968). In general the coat of the wild sheep comprises a hairy outer coat consisting of coarse kemps which obscures a fine woolly under coat (Figure 1), and the whole coat is moulted each spring (Ryder 1983). Wild sheep have black, brown, grey and white areas in the coat, the evolution of these many coat colours provided camouflage from predators in their natural habitats. In general, domestication has resulted in a reduction in the size of the horns, and a lengthening of the tail, as well as a change from a coloured, hairy, moulting coat to a white, woolly fleece that grows continuously (Ryder 1983).

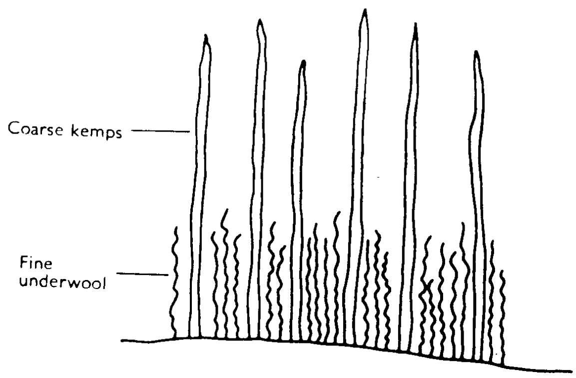

Figure 1. The double coat of wild sheep (Ryder & Stephenson 1968)

The development of the many different breeds of sheep we see today has largely been the result of selective breeding by man to produce various desirable traits and then fixing these traits through inbreeding. The continued existence of some of the traits of 'wild sheep' in many of today's sheep breeds (ie double coats, pigmentation and propensity to shed) may been due to these traits conferring an advantage to survival in many different habitats around the globe, or merely a perception on the part of the breeder as to their relative economic importance.

THE FOUR MAJOR FLEECE TYPES
There are four major fleece types; hair, long wool, double-coated and the Merino (Ryder and Stephenson 1968). These different fleece types are characterised by a large degree of variation in the size and shape of the various types of follicle, the number and arrangement of follicle groups within the skin, the type of fibre grown by the follicles and the characteristics of those fibres.

Follicle groups in the skin
The follicle group of wild sheep is characterised by a very large central primary and its two associated lateral primary follicles. Much smaller secondary follicles lie between the primaries (Figure 2). The large primary follicles grow coarse, heavily medullated kemp fibres, which form the outer coat while the secondary follicles grow fine non-medullated wool fibres. The skin of all breeds of sheep contain both primary and secondary follicles which are grouped in a similar 'trio' arrangement to that of the wild sheep. However, significant between and within breed differences occur which produce the four distinctive fleece types.

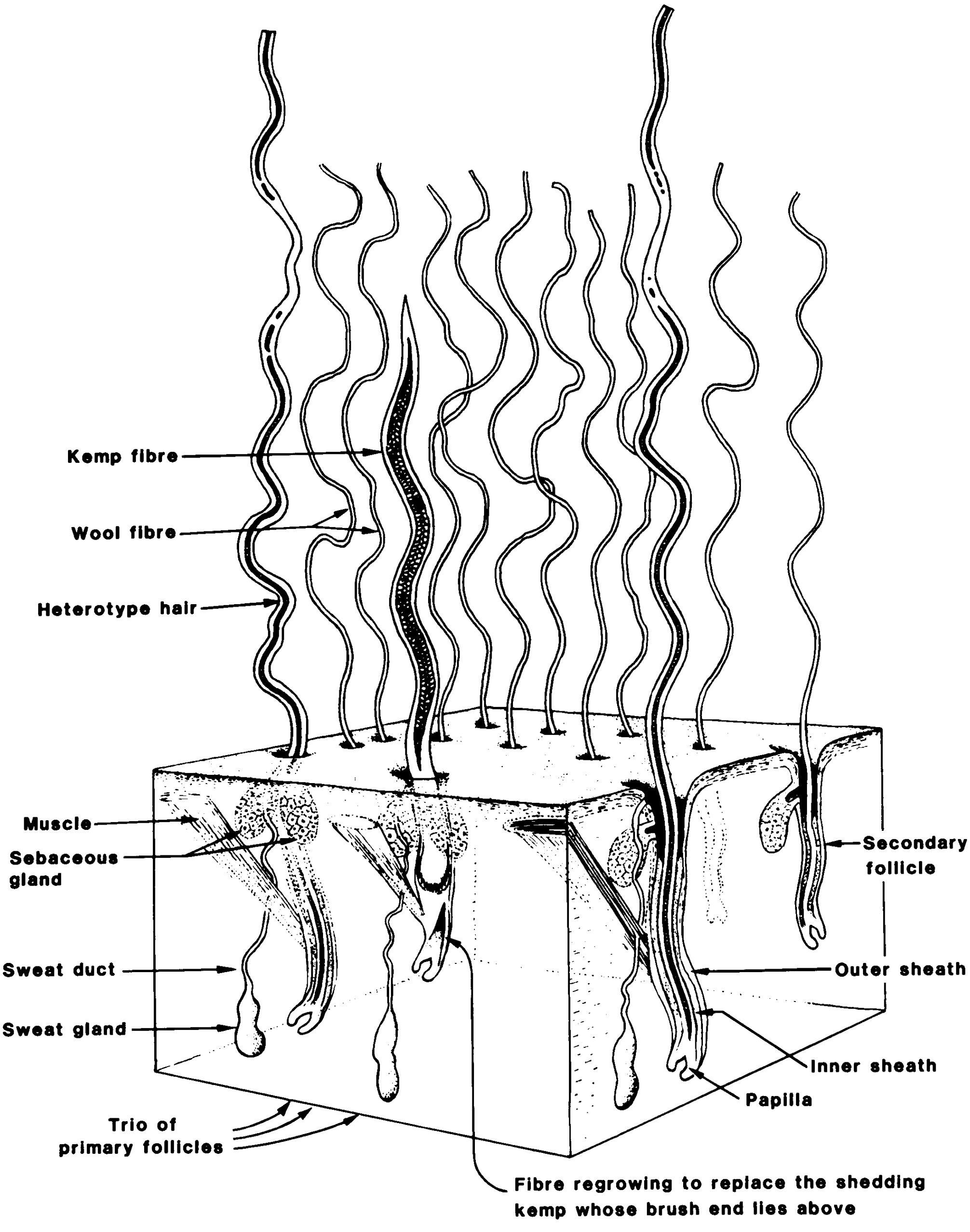

Figure 2. An idealised follicle group showing the different fibre and follicle types (Ryder and Stephenson 1968).

The principal cause of the different fleece types is variation in the secondary to primary (S/P) follicle ratio (Fraser and Short 1960; Ryder and Stephenson 1968). However variation in the density or number of follicles per unit area of skin, arrangement of follicles in the skin and the relative size of the primary and secondary follicles also play a role in determining fleece type. In general the more primitive fleece types such as the hair and double-coated types tend to have low follicle densities, a low S/P ratio and a large difference in size between the primary and secondary follicles. The Merino being the most highly developed fleece type, is characterised by high follicle density, a high S/P ratio with little size difference evident between primary and secondary follicles.

Fibre types and fleece structure

Four types of fibre have been recognised in adult sheep; these are hair, heterotype, wool and kemp (Lang 1950; Ryder and Stephenson 1968). The proportion of each of these in the fleece produces the characteristic fleece structure of a particular breed. A summary of the characteristics of each of these fibre types is given in Table 1. There are clearly significant differences between the four fibre types ranging from the type of follicle from which they most commonly grow to their microscopic structure and growth pattern throughout the year. Other fibre attributes such as dimensions, scale pattern and the incidence of medullation[1] can vary within a fibre type in response to environmental factors such as differing level of nutrition throughout the year (Ryder and Stephenson 1968).

Table 1. The major characteristics of the four fibre types found in the adult fleece

Fibre Characteristics	Fibre Type: Hair	Heterotype	Wool	Kemp
Follicular origin [f]	Primary, some in larger secondary	Larger secondary, some primary	Secondary	Central primary, some lateral primary.
Structure [b]	Cuticle, cortex and medulla.	Cuticle, cortex, sometimes a medulla.	Cuticle of scales and a cortex, sometimes a medulla in coarser types.	Cuticle, cortex and medulla
Scale pattern [b]	Mosaic, sections of irregular waves.	Irregular waved or non-waved mosaic along length.	Coronal, semi-coronal or irregular mosaic in fine wool to regular mosaic in coarser types.	Transitional along length. Regular mosaic at base, irregular waved mosaic at tip with near, smooth scale margins.
Medulla [b,c,f]	Fragmental, interrupted or continuous	Interrupted	Absent in fine wool, when present in coarser wool, fragmental, interrupted or continuous	Wide lattice
Appearance	Opaque	Opaque	Opaque	Chalky white
Cross-section [b,c,f,g]	Circular	Circular to irregular.	Circular to oval	Flat dumbbell shape
Longitudinal appearance [c]	Irregular diameter	Variable	Irregular diameter	Flattened areas
Root end [b]	Cut	Cut	Cut	Bulb or brush end
Tip end [b]	Cut	Cut	Cut	Long tapering
Crimp [d]	Absent	Slightly crimped	Highly crimped	Broad crimps
Growth	Continuous	Continuous	Continuous	Limited time, shed
Fibre length [e]	Long, 100 mm	Intermediate, 82 mm	Short to intermediate, 60 mm	Short, 56 mm
Fibre diameter [e]	Variable, 60 μm	Variable, 48 μm	Fine, <30 μm	Coarse, 80 – 100+ μm
Tensile strength [a]				Very Low

References: [a] Roberts (1926); [b] Wildman (1958); [c] The Textile Institute (1975); [d] Luniak, (1973); [e] Hatcher, (1991); [f] Ryder and Stephenson (1968); [g] Appleyard (1978)

Fibre shedding and fleece structure

Fleece structure may also be influenced by fibre shedding occurring at different times of the year. In primitive sheep breeds, seasonal moulting of the fleece produces large differences in fleece structure between seasons (Ryder and Stephenson 1968). In some domesticated double-coated breeds the capacity to shed has been retained. In these breeds there tends to be an autumn and spring shedding of

[1] **Medullated fibres** are those that have a central core of air. There are two broad types of medulla: a) unbroken in which the medulla is continuous along the fibre and b) broken or interrupted. The *unbroken* category includes the following common varieties found in sheep: i) lattice – the medulla is very wide in proportion to the width of the fibre and consists of a network of 'struts' of keratin which outline polyhedral shapes, each of which is continuous with its neighbours. A mixture of gases occupies the spaces within the fibre; ii) Simple unbroken – consists of a simple continuous central canal, thin or thick but not as thick as the lattice type. *Broken* medulla include the interrupted which is usually relatively narrow and is completely interrupted or bridged at regular intervals by cortical substance and the fragmental medulla the occurrence of which is fleeting occurring only irregularly as fragments in the centre of the fibre. (Wildman 1958)

primary fibres and a spring shedding of secondary fibres (Fraser and Short 1960). In other breeds such as the Merino fibre shedding is a rare event occurring only in response to severe nutritional stress (Doney 1966; Fraser and Short 1960; Lang 1964; Ryder 1967). Clearly the incidence and extent of fibre shedding will vary significantly between fleece types due to the differing proportions of the four fibre types that constitute the fleece. However, the incidence of fibre shedding of exotic breeds run under Australian conditions remains largely unknown. In Australia, the daylight hours and temperature range differences between seasons, which are known to trigger fibre shedding (Ryder and Stephenson 1968) may not be as extreme as those occurring in their native environments.

Crossbreeding between fleece types and fleece structure
Few studies of the effect of crossbreeding on fleece structure have been undertaken. Those published have produced variable results, most likely as a consequence of the degree of difference in fleece structure between the two breeds being crossed. Crosses between Awassi and Merino sheep produced significant changes in fleece structure of the progeny. As the proportion of Awassi genes in the crossbred progeny increased (ie from an F_1 through to various Awassi backcross genotypes), the percentage, length and diameter of hair, and to a lesser extent, kemp fibres in the fleece increased at the expense of wool fibres (Hatcher 1995). From this study it was concluded that the main effect of an increasing proportion of Awassi genes was to increase the degree of hairiness and medullation in the fleece. Fraser *et al.* (1954) made a similar conclusion when studying crosses between Romney sheep that carried the *N* and *nr* carpet wool genes and those that did not. Similarly crosses between the Merino and three native Norwegian breeds did identify changes in the percentage of medullated fibres in the fleece (Ronningen and Gjedrem 1970).

However other studies, have found little impact of crossbreeding on fleece structure. Lauroncik (1973) compared the fleece structure of pure Valachian sheep with those containing 25 per cent Leicester blood and found little difference in fleece structure with regard to the percentage of hair, wool or kemp. In this case it is likely that the Valachian and Leicester breeds have similar fleece structures, both being long wools, so that little difference would be expected to occur with crossbreeding.

Crossbreeding has been reported to alter the pattern of fibre shedding, which may also lead to differences in fleece structure. An investigation of F_1 Herdwick x Merino sheep showed that autumn shedding was reduced in comparison to the purebred Herdwick (Burns 1955). In the crossbreds the winter and autumn fibre shedding was reduced and delayed. Therefore the influence of the Merino on the F_1 generation was to direct the shedding characteristics toward that of the Merino parent (Burns 1955). In contrast the shedding characteristics of Mouflon x Merino sheep combined characteristics of both parents. The primary follicles of Mouflon x Merino progeny tended to retain the shedding characteristics of the Mouflon as the kemp fibres were shed, however there was little or no shedding of wool fibres from secondary follicles (Ryder 1973). Again, there is little information on the incidence of fibre shedding in fleeces of crossbred progeny resulting from Merino and exotic breed crosses.

FLEECE CLASSIFICATION OF AUSTRALIAN 'EXOTICS'
Each of the exotic breeds currently being run in Australia has distinct fleece characteristics and can be classified into one of the four fleece types.

Hair sheep
Hair sheep probably have the most in common with wild sheep in terms of fleece structure. The fleece of hair sheep is typically composed of a short kempy coat with a sparse undercoat of fine wool fibres (Ryder and Stephenson 1968). Although wild colour pattern in which the belly is white has mostly been lost, hair breeds exhibit a range of colours from black, through brown to white (Ryder 1983). Hair sheep typically have a skin follicle population that is very similar to that of wild sheep. They have a low S/P ratio with a large difference in size between primary and secondary follicles. The kemp fibres comprising the outer coat grow from the primary follicles, while the wool fibres originate from the secondary follicles.

The **Damara** fleece is a true hair type, with an outer kempy coat and with an inner layer of wool. The fleece is shed completely during the year and exhibits a range of different colours, tan, brown, black and white spotted (Douglas and Sommerville 2001; Ryder 1983). Young purebred Damara sheep tend to have a longer outer coat and higher proportions of wool fibres that they lose with age (Breeds of

Livestock 2002). **Dorper** sheep have a fleece of wool and kemp, which is shed if not shorn regularly (Douglas and Sommerville 2001). The breed has a characteristic colour pattern of a black head with the rest of the body being white, although a white headed Dorper has been produced by selective breeding. The **Van Rooy** (or White Persian) is also a hair type breed made distinctive by its lack of pigmentation.

Long wool sheep
The majority of British sheep breeds such as the Leicester, Lincoln, Border Leicester and Romney have the long wool fleece structure. These breeds have long fleeces of fairly coarse wool that tends to be lustrous (Ryder and Stephenson 1968). The staple length can be quite long, up to 200 mm, a consequence of which is that the staples tend to often hang in ringlets.

Double-coated sheep
The double-coated breeds also have similar follicle group pattern and fibre types to wild sheep. In these breeds however, long hair or heterotype fibres that grow for longer periods of time rather than being shed frequently have replaced the majority of coarse kemps grown from the primary follicles. This particular array of fibre types produces the characteristic appearance of the staple of double coated breeds, a conical structure with a woolly base and a pointed hairy tip (Ryder and Stephenson 1968).

The fleece of **Awassi** sheep and its various Merino crosses has been extensively studied. Awassi sheep have a typical double-coated fleece containing hair, heterotype, wool and kemp fibres in the approximate proportions of 45, 10, 39 and 6 % respectively (Hatcher 1995). Due to the low proportion of kemp fibres in the fleece, the Awassi has only a small number of fibres that have the potential to be shed. The characteristic colour pattern of the Awassi breed is to have coloured points (head, and legs) ranging from black, through brown to a roan type shading with a largely colour free fleece. In fact, pigmentation in the adult Awassi fleece is confined to the kemp fibre fraction of the fleece (Hatcher 1995). This is in contrast to the fleeces of Awassi lambs, which contain a significant percentage of coloured fibres in the hair, heterotype and kemp fibre fractions up to 3 - 6 months of age. After this time there appears to be a cessation of pigment production in the fleece bearing skin and combined with the existing fibre pigment fading and an increase in wool fibre production the adult colouration pattern is achieved. The various Awassi x Merino backcross genotypes (B_1, B_2, B_3) were found to have essentially the same fleece, fibre and skin characteristics as those of the purebred Awassi. However the first cross fleece was significantly different from both the Merino and Awassi in that it contained lower percentages of hair and kemp fibres, a higher percentage of heterotype fibres and contained pigmented heterotype and kemp fibres up to 21 months of age (Hatcher 1995).

The **Karakul** fleece is also of the double-coated type. The outer hairy fibres are quite long and lustrous. The overall fibre diameter of the fleece ranges from 16 to 158 μm depending upon the fibre type being measured with an average fibre diameter of 32 μm and a mode of 30 μm (Ryder 1968). The fleece is usually black, but red, brown and white variants have been observed (Douglas and Sommerville 2001). Traditionally, Karakul sheep have been kept for the production of lambskins for coat manufacture. The lambs are killed within 2 days of birth in order to preserve the curls that are a feature of the lamb birth coat (Ryder and Stephenson 1968). Most Karakul lambs are born coal black with lustrous wavy curls, with the face, ears and legs usually showing smooth sleek hair (Breeds of Livestock 2002). As the lamb grows, the curl opens and loses its pattern and the colour generally begins to turn brownish or bluish grey, getting grayer with age. The adult fleece has a low density, is lustrous and long usually with no crimp.

Merino
The Merino fleece type is very uniform and almost exclusively composed of wool fibres, although coarse heterotype fibres have been identified (Lang 1950; Marston 1955). Estimates of the frequency of these fibres in the Merino fleece vary between strains, flocks and body position. No non-kempy medullated fibres were found in fine or medium woolled Merinos and 0.03 - 0.05 % at the breech of coarse woolled Merinos (Lang 1950) while Gallagher and Yeates (1970) found anterio-posterior gradients of 0.17 - 0.28 and 0.11 - 0.28 % medullation in two Merino flocks. There has been no direct estimate of the proportion of kemp fibres present in the Merino fleece, but again they are only likely to

be present in small amounts and to vary between strains and flocks. The Merino type fleece is the most highly selected fleece type and therefore is thought to be completely devoid of any seasonal fibre shedding (Ryder 1978). Studies in which evidence of fibre shedding were found concluded that shedding in the Merino appears to be a response to changes in nutrition, which occurs with changes in seasons, rather than non-nutritional seasonal factors (Doney 1966; Fraser and Short 1960; Lang 1964; Ryder 1967). The **Dohne** and **South African Mutton Merino** breeds have the Merino fleece type. The South African Mutton Merino is capable of producing good volumes (4kg) of medium to strong wool (Breeds of Livestock 2002).

Obviously there are large differences in the fleece structure and hence particular fleece characteristics of the range of exotic breeds currently run in Australia. The breeds differ in the proportion of each of the four fibre types that constitute the fleece and hence their pigmentation and shedding characteristics. Therefore, classifying all of these breeds in one group as 'exotics' and regarding them collectively in terms of their impact upon sheep and wool production in Australia would be a mistake. This type of classification fails to recognise the particular attributes of each breed and thus doesn't allow a balanced examination of their individual impact to be made. A more precise determination of the impact of these various breeds on the Australian sheep and wool industry requires a much greater understanding of the biology of the various breeds and their respective fleece types under Australian conditions including changes in fleece structure, fibre shedding and pigmentation characteristics. This includes the pure breeds themselves as well as the range of crosses with the Merino that have and will continue to occur as a result of the breed introduction and grading up process of multiplying the genetic material of each breed.

CLIP CONTAMINATION

In order to discuss the potential of the exotic breeds of sheep for clip contamination and place the risk they pose into perspective, it is necessary to identify the current contamination status of the Australian wool clip, the sources of contamination, acceptable industry limits on the various contaminants and the persistence of contaminant fibres during wool processing.

The current contamination status of the Australian wool clip

Contamination of the wool clip by non-wool articles is probably the single biggest issue for the quality of the Australian wool clip and has been so for many years (Australian Wool Exchange 2001). The current Code of Practice for the Preparation of Australian Wool Clips for both The Woolclasser and The Producer (Draft) provide clear guidelines to follow during a pre-shearing inspection of the shed and associated facilities in order to prevent contamination of the wool from non-wool articles. In addition, AWTA Ltd provides a contamination screening service as part of the core testing procedure, however this does not provide any guarantee that the lots are contamination free (Australian Wool Exchange 2001). Despite these procedures non-wool contamination is still a reasonably frequent occurrence.

Prior to 1999 when import regulations were changed to only allow nylon wool packs into Australia, the overwhelming source of contamination in the Australian wool clip was high density polyethylene (HDPE) and jute fibres originating from woolpacks (Australian Wool Corporation 1993; Elders 1993). The second most common source of contamination at the time was vegetable matter. It is now reasonable to conclude that with the virtual elimination of HDPE wool packs from Australia that vegetable matter is the current major source of contamination of the Australian wool clip[2]. Presale tests for vegetable matter have been operating for over 40 years and provide wool buyers with comprehensive information on the both the amount and type of vegetable matter present in each sale lot. As a result, clear market signals exist as to the discounts applied to wool with various levels of vegetable matter contamination.

Contaminant fibres of animal origin are the next major source of contamination of Australian wool. These include urine stained, pigmented and medullated fibres. Of these three categories, urine stained fibres have been identified as the major contaminant from Merino sheep (Foulds 1983; Foulds *et al.*

[2] However, it is important to recognise that the problem of polypropylene twine from hay bales continues to exist, despite moves to use different colours of twine or replace it with wool twine or plastic wrap.

1984; Way 1979). Crutching sheep within 3 months of shearing has been found to greatly reduce the incidence of stain but provides no absolute guarantee that the fleece is stain free (Australian Wool Exchange 2001). Again compliance on the part of the Woolclassser and Producer (Draft) with the Code of Practice for the Preparation of Australian Wool Clips should greatly reduce the incidence of urine stained fibres contaminating white wool.

In comparison with the above-mentioned sources of clip contamination, pigmented and medullated fibres are currently only a very minor source of contamination of the Australian wool clip. The incidence of sale lots carrying the Y_1, Y_2 or Y_3 suffixes[3] has been of the order of 0.003 to 0.004% of all wool sold through auction since the introduction of the scalable Y suffixes in July 1999 (B. Brice *pers. comm.*). An examination of processors lots from the major wool selling centres in Australia indicated that the incidence of medullation was 1.1 % in the majority of the lots and up to 3.3 % in an individual lot (Gallagher 1970).

There is no existing pre-sale test for the presence of contaminant fibres of animal origin, whether urine stained, pigmented or medullated. The wool industry currently relies on quality assurance practices in sheep breeding as well as those outlined in the Code of Practice for the Preparation of Australian Wool Clips to indicate the risk of contamination with fibres of animal origin. This risk level is communicated to the wool buyer and wool processor through via the AWEX_ID description of each sale lot published in the sale catalogue. A recent trial initiated by AWTA Ltd and the South Australian Research & Development Institute (SARDI) assessed the potential to develop a pre-sale test for animal fibre contamination using core samples of suspect sale lots. A range of methods were examined including visual observation, image analysis, OFDA, near infrared reflectance, UV florescence, flotation and measuring the coefficient of fibre diameter. Of these methods, only a simple visual inspection of the cleaned cores by a trained wool operator using a CSIRO Dark Fibre Detector was proven useful (Fleet *et al.* 2001). Despite the demonstrated subjective nature of this measurement technique it was concluded that it would be technically feasible for AWTA LTD to provide guidance about the level of dark fibre contamination in Merino fleece wool using this method. However, it would not be commercially feasible to routinely provide this service for all presale lots, or even a significant subset of presale lots, given the large degree of subjectivity, high labour input required, potential for cross contamination and long turnaround time (Sommerville 2001).

At present a collaboration between AWTA Limited, CSIRO Textile and Fibre Technology and the SARDI is seeking industry support for the development of a novel objective test which will provide a quantitative indication of the number of dark fibres in a sale lot (P. Sommerville *pers. comm.*). This program has received in principal support from Australian Wool Innovation Limited and a full proposal is currently under development. This new test method is based on a novel modification of existing systems and techniques and is likely to be available within 12 months. The new test method will no doubt be supported by wool producers interested in demonstrating that their clips are free from dark fibre contamination. However whether the test will be widely adopted by the wool industry or merely applied to those sale lots carrying the Y suffix remains to be seen. Considerations such as the cost per test and its perceived benefit to producers, wool buyers and processors will have an impact on its adoption throughout the industry.

Therefore, it appears that the current situation of the application of quality assurance principles during the sheep breeding, animal management, shearing, clip preparation and sale to identify the risk of animal fibre contamination and communicate this risk to the wool buyer and wool processor will continue, at least in the sort term pending the development of the novel pre-sale test for dark fibres.

Clip contamination and wool processing

There is an extremely wide span of ‘acceptable’ limits of animal fibre contamination in raw wool, ranging from a few parts per million to an often quoted upper tolerance for critical en-uses of 100 dark fibres per clean kg (Fleet 2000). This wide range is largely a result of the variability of the upper limits

[3] The use of the Y suffix denotes a risk of contamination from pigmented fibres. Y_1 is used whenever pigmented fibres are present in small amounts (1 or more fibres). Y_2 is used when larger numbers of these pigmented fibres are evident and Y_3 is used when the lot of wool is clearly prepared as a black (pigmented) line or is a mixture of pigmented and white wool (Australian Wool Exchange 1999).

quoted for contaminant fibres at the various processing stages (Table 2). There are many factors that combine to produce this wide range of ‘acceptable limits’ of animal fibre contamination. They include the characteristics of the contaminant fibre itself (ie primarily the colour or the difference in colour between the contaminant and the end-product, fibre diameter and length) (Foulds 1988; Fleet and Foulds 1988) as well as the yarn and fabric structure of the end-product (Foulds *et al.* 1984).

Table 2. Upper limits for dark fibres at the (a) top, (b) fabric and (c) garment stages of processing.

Reference	Production type	Dark fibre limits
(a) Top		
Bell (1978)		3 - 10 per 100g
Keynes (1986)*	All fleeces top	1-2 per 100g
	Fleece/pieces	4-8 per 100g
	Pieces/bellies	10-15 per 100g
	Stain top (off colour)	No limit
Fleet *et al*. (1986)	White, pastel shades	10 per 100g
Fleet and Foulds (1988)		1-100 per kilo
Foulds (1989)		100 per kilo
Turk (1992)		1 per 100g
G.H Michell[@]	Best topmaking	1 per 100g
	Good topmaking	5 per 100g
	Average topmaking	5-20 per 100g
	Discoloured	100 per 100g
	Stains	No limit
Woolworth (India) Ltd[^]		Commercially free
Toyoshina Spinning Co.[^]	19.5-21.0μm	under 0.2 per 20g
	21.1-22.5 μm	under 0.5 per 20g
	22.6-25.0 μm	under 0.5 per 20g
Cleyn & Tinker Inc[^]	Clean tops	2 per 250g
	Reg A top	50 per 250g
Cheil Industries[^]	Spinners/best topmaking	0 per 10g
	Good topmaking	less than 0.2 per 10g
	X-bred	less than 0.4 per 10g
Australian Spinners Standards[#]	All micron range	less than 30 per 100g
Japanese Standards[#]		0 -2 per 10g
(b) Fabric		
Nilon (1986)	Worsted woven	1 per metre
Foulds (1988)		3 per metre
Foulds *et al*. (1991)	White knitted	100 per kilo
(c) Garment		
Foulds, *et al*. (1984)	White and pastels	1-3 per square metre per garment

* All fleeces top are typically 65-70mm hauteur for top grade suiting and high grade fashion knitwear, Fleece/pieces are typically 60-63 mm hauteur for the general worsted trade, Pieces/bellies are typically 53-58 mm hauteur for the lower end of the worsted trade and stain tops are typically 50-55mm hauteur for the cheap woven and knitted goods of dark colours.

[@] Specification provided by Judy Turk, Michells Woolcombers

[^] Specifications provided by Riverina Wool Combing

[#] Specifications provided by Australian Wool Corporation

Clearly the seriousness of dark fibre contamination is dependent on the wool processing system and end use of the garment. It is interesting to note that none of the specifications make the distinction between urine stained and pigmented fibres. Compounded with the variability of the upper limit for dark fibres at each processing stage is the fact that at present there is no simple reliable test for dark fibres. Any test that is performed has the potential for a large sample error and it is possible for two samples from the same blended batch to give different dark fibre results when tested by the same laboratory (Keynes 1986). Further development and application of the proposed pre-sale test for dark fibres to various stages of wool processing may be of benefit.

Loss of contaminant fibres during processing

There have been no studies that have specifically investigated the persistence of animal contaminant fibres during wool processing. Limited information has been obtained from experiments involving Merino wool with known levels of animal fibre contaminants arising from experimental conditions that was processed into worsted top, yarn or fabric. One such study found the total concentration of

Merino pigmented fibres in tops was higher, by a factor of 2, than in the raw fleece (Fleet and Foulds 1988). Likely reasons for the increased concentration of pigmented fibres in the top included fibre breakage during processing and the removal of staple tips during fleece sample preparation. Additionally, superior viewing conditions for viewing the dark fibres in the wool top, similar fibre characteristics between the contaminant and the wool bulk and observer differences were also thought to contribute to the easier detection of contaminants in top (Fleet and Foulds 1988). Hatcher *et al.* (1999) found that contaminant animal fibres which were of similar structure to the wool bulk, such as pigmented wool fibres, did persist during worsted processing and appeared as contaminants in top and fabric. However, there was no evidence of the increase in concentration after early stage processing as identified by Fleet and Foulds (1988).

Contaminant animal fibres which are significantly structurally different from the wool bulk, such as kemp and broad medullated fibres be they hair, heterotype or kemp, are able to be removed with varying success during worsted processing. More than 97% of pigmented kemp fibres from Awassi sheep present in the Merino greasy fleece were lost during processing (Hatcher *et al.* 1999). The central core of air in medullated fibres in general and kemp in particular results in these fibres having low tensile strength (Groff 1983) thus increasing the likelihood of them breaking during early stage processing. During the carding and combing processes the majority of these fibres break and are removed with the card and noil waste (Turpie 1971; Groff 1983). A comparison of the lengths of medullated fibre in top and noil indicated that the shorter, coarser medullated fibres went into the noil and the longer, finer medullated fibres went into the top (Turpie 1971). This is most likely the result of the finer medullated fibres not being sufficiently different from the wool bulk to be ejected during processing. Coarser kemp fibres therefore generally do not survive processing to contaminate yarns and fabrics. However finer kemp fibres may survive processing to a greater extent as a microscopic study of contaminants found in fabric did identify the fibres as kemp (Appleyard and Perkin 1965). Nevertheless very few wool processing specifications include a limit for medullated fibre and kemp.

Each of the aforementioned studies was concerned with the worsted processing system, the most recent (Hatcher *et al.* 1999) being conducted more than five years ago, the other studies are at least a decade or more old. A number of recent advances in processing technology such as high speed carding, increased speeds of combing and spinning as well as technology such as SiroCLEAR™ which can detect and remove dark fibre contaminants from yarn during winding have been developed and adopted by the wool processing industry. The impact of these on the persistence of animal contaminant fibres through the worsted processing system is unknown. Additionally, there have been no studies investigating the persistence of animal contaminant fibres in the woollen processing system. While it has been thought that animal contaminant fibres would persist in the woollen system due to its less efficient carding process and no combing phase, the fate of contaminant fibres in this system remains largely unknown. Similarly the visibility of animal contaminant fibres, and hence their potential identification in woollen yarn and fabrics, is unknown although it is likely to be low due to the more bulky and less structured yarn and fabrics typically produced by the woollen system.

It is clear that a well-structured research project looking at the persistence of animal contaminant fibres in both the worsted and woollen systems and their visibility in various yarns and fabric structures is warranted. The animal contaminant fibres would need to exhibit a variety of pigmentation, fibre diameter and length as well as medullation characteristics and be sourced from the range of breeds exhibiting these fibres in their fleece.

POTENTIAL CONTAMINATION ARISING FROM EXOTIC BREEDS OF SHEEP

The importation of Awassi sheep into Australia in 1987 and subsequent imports of other exotic breeds since that time has led to concerns being raised regarding the contamination of the Merino clip from with undesirable fibres both from the exotic breeds themselves and their crosses with Merino ewes. The pigmentation characteristics of some of the exotic breeds of sheep and the presence of medullated fibres in their fleece are the basis behind the concerns surrounding their commercial development in Australia. It is thought that the presence of these breeds in Australia will increase the level of animal fibre contaminants, both pigmented and medullated, in the Merino wool clip.

Contamination or transfer of pigmented wool, kemp and medullated fibres may arise from fibre transfer within a sheep itself or within a group of sheep whether they are of the same breed or of two different breeds. The former case has been established by a microscopic study of short animal fibres appearing as contaminants in wool cloth (Appleyard and Perkin 1965). The authors found that fibres from the face, legs, and axillary (angle between the fore-limb and the body) and inguinal (groin) regions of Romney Marsh and Swaledale sheep were similar to the contaminants in the cloth produced from fleeces of these sheep. This indicates that kemp and pigmented fibres are transferred from the non-wool growing areas of the sheep such as the face, legs and belly into the wool growing areas.

The cause of fibre contamination – direct contact between sheep

A number of studies of contamination of Merino fleeces by pigmented, medullated and kemp fibres have now been conducted both in Australia and overseas. Each of these studies has shown that direct contact between sheep is required for contaminant fibre transfer between sheep to occur (du Toit 1990; Fleet *et al*. 1986; Fleet *et al*. 2001; Johnston and Larson 1957; Hatcher *et al*. 1999; Hatcher *et al*. 2000a; Hatcher *et al*. 2000b; Hatcher *et al*. 2000c; Rose *et al.* 2000).

The most common process of importing exotic sheep breed into Australia appears to be the collection of purebred embryos and their implantation into and subsequent rearing by Merino ewes. Multiplication of the exotic genes is generally undertaken through a process of grading up using the abundant and relatively cheap Merino in an F_1 cross followed by a succession of backcrosses to the parental breed. Grading up was used for the introduction of Awassi genes into Australia and continues to be used as a gene multiplication tool in the commercial development of the breed (Hatcher 1995). The process of grading up of exotic breeds is fundamental to the fibre contamination concerns of the Australian wool industry as direct contact between sheep is an essential component of the process, during mating as well as during the birth to weaning period of Merino x 'exotic' crossbred lambs.

The consequence of mating of Awassi (Hatcher *et al*. 2000a), Damara (Fleet, *et al*. 2001; Rose *et al*; 2000), Dorper (du Toit 1990; Rose *et al*. 2000), Suffolk (Hatcher *et al*. 2000a) and Ronderib-Afrikaner (du Toit 1990) rams to Merino ewes has been established. In the majority of cases, mating the exotic ram breeds to Merino ewes did result in the transfer of pigmented, medullated and kemp fibres into the fleeces of the Merino ewes. Both the numbers of fibres and the fibre type transferred differed between the studies, which was largely due to differences in the fleece of the ram breeds themselves. However, management factors such as the ratio of rams to ewes and the length of the joining period would obviously influence the amount of contact occurring between rams and ewes and hence the number of contaminant fibres transferred.

The use of artificial insemination (AI) of Merino ewes with semen from exotic rams would largely overcome the need for physical contact between rams and ewes and effectively remove mating as a fibre contamination threat. However, for various reasons whether merely as a 'back-up' to an AI program or simply cost, AI may not be an option for all producers running exotic breeds. An important outcome of the above mentioned studies was that the number of contaminant fibres remaining in the fleeces of the Merino ewes decreased with time after the removal of the rams (Hatcher *et al*. 2000a; Rose *et al*. 2000). This finding led to the recommendation of a 'withholding' period of two months between mating and shearing of the Merino ewes. The two-month time period is recommended so that the level of contaminant fibres remaining in the Merino fleece is likely to pose a very low contaminant risk if at all.

As there is no practical alternative to Merino ewes raising crossbred lambs between birth and weaning this time period represents the greatest threat in terms of the contamination of the Merino clip with pigmented, medullated and kemp fibres. The close physical bond between the ewe and lamb during the birth to weaning period has been found to produce extensive fibre transfer between the lamb and the ewe for a variety of Merino and exotic breed crosses (du Toit 1990; Fleet *et al*. 2001; Hatcher *et al.* 2000b; Rose *et al*. 2000; Van Zyle 1995). Again not surprisingly, there was significant variation between the studies in the amount of fibre transfer between the lamb and ewe. Breed differences in the pigmentation and medullation characteristics of the lamb's fleece and the extent and timing of shedding of fibres from the lamb's fleece are obvious causes of this variation. Other factors including the number of lambs reared by each ewe and the length of the birth to weaning period are also important. The loss of fibres with time after weaning was identified in some of the above studies (Hatcher *et al.* 2000b; Rose *et al*. 2000) but not others (Fleet *et al*. 2001). Again it is likely that breed differences in the characteristics of the lambs fleece are responsible for this difference.

Management options to minimise contamination from exotic breeds of sheep
It is obvious from the studies of fibre transfer between sheep that significant differences exist between exotic breeds in the number and type of contaminant fibres transferred into the Merino fleece. While differences in the fleece of the exotic breed itself can explain the majority of this variation a number of other factors apart from breed per se will also have an impact. Obviously any factor which influences the degree of direct contact between sheep will be important. These include the size of the mating or lamb rearing paddocks, the stocking rate of these paddocks, the proportion of rams mated to ewes, the number of ewes rearing multiple lambs and even incidences of mustering and moving mobs of mating groups or lambing ewes.

Additionally, the impact of management and environmental factors on fibre transfer between sheep remains largely unknown. Management factors such as the timing of shearing and wool length of the sheep (both exotic and Merino) and the characteristics of the Merino fleece itself, such as staple strength and vegetable matter contamination each have the potential to influence the amount of fibre transfer occurring between sheep. Additionally environmental factors such as the pasture composition, number and location of watering points, lice and itch mite infestation and even blowfly strike may also be important.

It would be impossible for one or even a series of research projects to adequately quantify the contamination potential of each of the exotic breeds presently run in Australia. Given the significant differences in fleece structure between the breeds and the wide scale of breed, management and environmental factors that have the potential to affect the fibre transfer process it would be an ambitious project which attempted to cover all eventualities. It would seem that a far better use of experimental resources would be achieved through a better understanding of the biology of the fleeces of the exotic breeds and their Merino crosses. Furthermore a focussed effort to determine the persistence of animal contaminant fibres in both the worsted and woollen processing systems would allow the ultimate impact of animal fibre contamination to be better quantified. This would lead to the refinement of the current risk levels posed by the various non-Merino breeds of sheep in the current Code of Practice for the Preparation of Australian Wool Clips (Australian Wool Exchange 2001). Refinement of the risk levels posed by each of the exotic breeds is imperative at least until the pre-sale test for dark fibres currently under development becomes a commercial reality.

MARKETING EXOTIC FIBRE

Fibre from exotic breeds must be marketed and sold separately from Merino fibre. This includes fibre from the exotics themselves as well as that from Merino sheep that have been mated with or run in direct contact with exotic breeds.

Exotic breeds
The level of organised marketing of fibre from exotic breeds differs depending on the breed itself and also on how the genes of the exotic breeds are controlled.

Awassi. Over 95% of purebred and Awassi Merino cross fleeces grown in Western Australia are marketed through Dyson Jones Wool Marketing Services in Western Australia (K. Dyson, *pers. comm.*). Since the introduction of Awassi sheep into WA in the early 1990's Dyson Jones have marketed in excess of 20,000 bales of Awassi fleece ranging from purebred fleeces to the various crosses with the Merino. Dyson Jones hold blind tender sales for Awassi and Awassi cross fleeces every three months at which about 1,000 bales per sale are offered to the trade. This wool is sold using a separate show floor from that used to sell Merino wool and the Awassi and crossbred wool is offered with accurate descriptions as to the content of each sale lot, including the genetics quality and colour. During this time, Dyson Jones have had only one problem with contamination (K. Dyson, *pers. comm.*). In this instance the problem arose from insufficient classing standard rather than a breed problem as one bale of Merino wool was pressed without the classer/presser ensuring that the press had been empty. The Merino wool was pressed on top of a butt containing black wool from a previous shearing which had been inadvertently left in the press.

These Awassi and Merino crossbred sales are well patronised by wool buyers, from both WA as well as from the eastern states of Australia. Prices for Awassi and Awassi x Merino cross fleeces range from 80 - 90c/kg greasy for inferior types to in excess of 250c/kg greasy for the higher quality lines. Interestingly the price trends for Awassi and crossbred wools closely follow the movements in the market indicators for Merino wool, experiencing the same rises and falls. It is likely that in times of high Merino prices some substitution of Awassi and crossbred wool occurs by wool buyers with the higher prices for inferior Merino types such as the shorter and perhaps stained Merino pieces and locks. The majority of the Awassi and crossbred fleeces is sold to buyers and processors from India and China as well as to various Australian interests. The fibre diameter of the Awassi and crossbred wool ranges between 24 and 29 μm with the majority being between 25 and 26 μm. This renders the wool unsuitable to be used as the sole input for carpet manufacture, which requires wool greater than 32 μm. However the Awassi and crossbred wools are being blended with coarser types for carpet manufacture. Awassi and crossbred wool destined for India is manufactured into wall hangings and rugs. The end use of the wool sold to China is unknown, although the Chinese market displays strong interest each time the wool is offered for sale. The attractiveness of the Awassi and crossbred wool to the Chinese trade may well be due to its relatively low price compared with that of inferior Merino types. A major end use for the Awassi and crossbred fleeces, particularly the short, coloured and stained lines is insulation. Insulation manufactures can source this wool at a lower price than that of other types of wool and still produce a 100% wool product.

Damara. Fleeces from purebred and higher Damara x Merino crosses are shed periodically throughout the year and as a consequence there is no need to shear or market any fibre. However, it is necessary to shear the F_1 Damara x Merino cross. The fleeces from these crossbreds are typically very short (between 30 and 40 mm in length) and relatively coarse (27 - 28 μm) with a large coefficient of variation in fibre diameter (R. Myers *pers. comm.*). The F_1 Damara x Merino fleece is only available for marketing in very small quantities, the largest lot to date has been only 9 bales, and attracts little interest from the wool trade. Typical prices range from 35c to $1/kg greasy.

Karakul. In Western Australia Karakul and Karakul x Merino crossbred fleeces are largely marketed through Elders Limited. Tender sales for these lots are held every 6 to 8 weeks with about 300 bales on offer per sale (T. Smith *pers. comm.*). The Karakul fleece is similar to that of the Awassi although more highly coloured. The F_1 fleece Karakul x Merino crossbred fleece has an average fibre diameter of about 20 - 21 μm with a greater than 40 % coefficient of variation of fibre diameter. Higher order crosses (ie B_1, B_2 etc) have a similar appearance and characteristics as the pure Karakul fleeces. Prices for pure Karakul fleece, which averages approximately 32 μm, are in the range of 180c/kg greasy while prices for the F_1 cross tend to be around 70c/kg greasy. The majority of Australian Karakul fleece production is sold to Indian interests and is used in carpet and rug.

Fleeces shorn from the various Merino type exotics such as the **Dohne** and **South African Mutton Merino** are sold through the existing systems that are in place for marketing Merino fibre. As their fleece characteristics are essentially the same as medium to broader wool Merinos the full suite of objective measurements applied pre-sale to Merino sale lots are applied. No distinction is made within the AWEX-ID system for these Merino-like breeds (Australian Wool Exchange 1999) and as a result no specific wool price information is available specifically for either the Dohne or the South African Mutton Merino.

Merino wool grown in association with exotic breeds
In addition to the introduction of the Y suffix to denote sale lots which carry the risk of pigmented fibre contamination (Australian Wool Exchange 2001), the Australian Wool Exchange (AWEX) has developed 'good practice options' and made changes to wool selling rules to help manage the fibre contamination risk. AWEX has advised its members to abide by various 'good practice options' when dealing with wool at risk of pigmented fibre contamination (Australian Wool Exchange 2000). These good practice options range from ensuring that shearing stationary includes space for the producer and/or woolclasser to indicate the risk of pigmented fibre contamination to detailing procedures to follow when a risk of fibre contamination is present. Whether this risk is identified by the woolclasser or the broker knows that exotic breeds are run on a particular property regardless of the woolclasser or producer declaration is immaterial, the same procedures must be followed.

The amendments to the wool selling rules seek to improve the capacity of AWEX and its broker and private treaty merchants to deal with the risk of pigmented fibre contamination in wool offered for sale. Black wool and wool which contains or which may contain genetically pigmented wool (ie those lots which carry the Y_2 or Y_3 suffixes) must be isolated from and displayed in a different section of the showfloor, separated by at least an aisle width from other wool (Australian Wool Exchange 2002). Sale lots carrying the Y_1 suffix are displayed on the main floor. This rule change seeks to minimise any cross contamination occurring between Merino sale lots with and without the various Y suffixes. It is important to note that the origin of the pigmented fibre risk is not important. It is irrelevant whether the pigmentation risk arises from black Merino wool, black wool from various established terminal sire breeds or wool from the exotic breeds. The distinction is made on the basis of the Y suffix assigned to that particular lot.

The incidence of Merino sale lots carrying the Y suffix and sold directly through the auction system is low, generally less than 3 lots per sale if they occur at all. These sale lots are detailed in a separate section of the wool brokers' sale catalogue and are either sold by separation, through tender sales or offered through electronic selling systems. The sale outcome of these lots is reported in the normal market reporting system. Due to the low incidence of these lots, no market reports can be generated which provide specific details of prices received and thus allow a comparison with prices received for sale lots with similar raw wool characteristics but that do not carry the Y suffix. However various brokers with experience in dealing with Y suffix sale lots indicate that these particular lots attract price discounts of between 0 to 5% (R.Myers *pers.comm.*) or 5 to 20% (T. Smith *pers. comm.*). It is important to note that these price discounts are extremely variable and tend to fluctuate with wool buyers perceptions of wool supply and demand and the various levels of risk acceptable to their clients.

CONCLUSIONS AND RECOMMENDATIONS

- There is a requirement for a greater understanding of the biology of the exotic fleeces in Australian conditions as well as the biology of their Merino cross fleeces.
- The various fleece types and particular characteristics of the each of the exotic breeds gives them different potential to adversely impact on the Australian Merino wool clip.
- It is impossible to adequately experimentally replicate all potential situations of fibre contamination. A more useful research project would be to develop quantitative information on the persistence of exotic fibres in both the worsted and woollen processing systems.
- Development of the novel pre-sale test for dark fibres is essential in order to reinforce the benefits of the current QA systems for declaring the risk of dark fibre contamination to wool buyers and processors.

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