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Modelling Regional Impacts of Radioactive Pollution on Permanent Grassland

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Abstract: The objective of this study consists in evaluating the sensitivity of the first part of the die grass-milk with respect to an accidental radioactive discharge. We want to know if a single uniform deposit would involve a homogeneous contamination of the grazing grass on the scale of the whole French territory. The study was based on the ASTRAL model, a computer code developed by the IRSN which makes it possible to evaluate the transfer of the radio nuclides in the terrestrial food chain following an accidental atmospheric emission. The way of transfer of ASTRAL on which the study focused is the transfer of the deposit to milk, via the grazing grass ingestion. The sensitivity of this way of transfer relies on several parameters: interception capacity, yield, cows food rates and dates of setting to grass. Methodology thus consisted in regionalizing these parameters. The software STICS, developed by the INRA (Avignon Centre) was then used to regionalize the values for the retention and the yield. This model proposes a daily follow-up of the leaf area index which has been correlated with interception capacity and with the production of fresh biomass (yield).

Key words: Accidental discharges, agricultural contamination, grazing grass, permanent grassland, cows, radio ecological sensitivity, SENSIB, regionalization

INTRODUCTION

The radiological consequences of radioactive releases, as shown, in particular, by feedback relating to the Chernobyl accident, highlight the fact that the consequences of an industrial pollution on man and the environment depend not only on the extent and nature of this pollution but also on the territory that is polluted (Mercat-Rommens and Renaud, 2005). Whether expressed in economic, toxic or health risk terms, these consequences can be more or less detrimental depending on the features of the environment affected (environmental parameters) and the usage of this environment by man (human parameters). Urban, farming, forest, river, lake, sea or mountain environments show different pollution sensitivity levels and within these major environmental classes, the response or reaction to a pollution event is determined by different natural or human factors, specific to the ecosystem in question. For example, in a farming region, the type of production is a significant sensitivity factor. For the same surface area affected by a given pollution event, wheat and milk products will show very different respective contamination levels and time response. The remanence of this contamination in successive crops will also strongly depend on the soil characteristics. Generally, a territory's specific sensitivity to the pollution will be determined by the features intrinsic to its ecosystem, which has an influence in pollutant transfer. The same effect is observed with human factors such as farming methods (use of fertilizers, irrigation, sowing periods) or zootechnical practices (animal feeding regime, animals housed indoors or kept outdoors). A territory's radio ecological sensitivity is dictated by two components: environment and human factors.

Although we can establish that a territory may be susceptible to pollution it receives, it remains difficult to compare overall sensitivity between different territories. It is worse to have a high pollutant inventory in a natural space where there is little human influence, or to have a low concentration of the same pollutants in a water course intensively used for irrigation? Radio ecological

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sensitivity is a concept to evaluate the intensiveness of a territory's response to a pollution event. Since 2003, the French Institute for Radioprotection and Nuclear Safety (IRSN) with financial support of ADEME (French Agency for the Environment and Energy Management) has been running a cross-organizational project entitled SENSIB (an acronym for the French Sensibilité, referring to radio ecological sensitivity) (Mercat-Rommens and Renaud, 2005). The goal is to develop a standardized tool with a single scale of values to describe and compare the sensitivity of various environments to radioactive pollution, thereby providing a classification of the territory based on its intrinsic features (annual rainfall, feeding practices, soil type etc.).

This study focuses solely on the agricultural aspects of the SENSIB project. The object is to develop a method for classifying agricultural areas by their sensitivity to atmospheric radioactive pollution. Indeed, after the accidental phase, during which radio nuclides may be released into the environment, it is necessary to analyse and assess what will occur during the ensuing post-accidental phase. Firstly, the factors likely to increase or reduce the consequences of the pollution event will be identified, characterized and ranked, in order to develop a system of indices to be used for operational classification. The study aims to analyse the milk industry's sensitivity to accidental radioactive releases and establish whether a uniform, localized deposition would entail an identical contamination of milk production on a national scale. The study uses the ASTRAL model (Assistance Technique en Radioprotection post-Accidentelle), a computing code developed by the IRSN, which enables radio nuclide transfer to the terrestrial food chain following an accidental atmospheric release to be assessed (Mourlon and Calmon, 2002). What is sought is the effect of regionalisation of the ASTRAL model parameters on the specific activity in farm produce. In this study, the agricultural productions analyzed are the animal fodder grown in a permanent meadow subject to an accidental atmospheric caesium 137 (^{137}Cs) deposit and the ^{137}Cs concentration in the fodder at the time of its ingestion by the animal is determined. The STICS-Prairie software (Simulateur mulTIdisciplinaire pour des Cultures Standard, applied to meadows (prairie in French)) from INRA (Brisson *et al*., 1998; Brisson and Mary, 2002) was used in order to identify regional (environmental and agronomical) factors likely to significantly influence contaminant transfers in the food chain. In fact, this model provides a day-by-day estimate of the leaf area index, a variable which could be correlated with various radio ecological parameters in the ASTRAL model. Besides, coupling the radio nuclide transfer in the food chain model (ASTRAL) and the STICS model, will provide a comparison between the generic parameter values used in ASTRAL and the values obtained with the STICS model, taking into account three sources of regional variability: weather conditions, soil type, technical management. This type of coupling could improve the knowledge of the parameters used in radioecology.

MATERIALS AND METHODS

IRSN's radio ecological model, ASTRAL: ASTRAL comprises a calculation module involving geographical and radio ecological databases (radio nuclide transfer parameters in the environment), enabling the impact of radioactive deposits on agricultural produce (specific activities), agronomic resources (areas and quantities affected) and populations (doses received) in areas affected by a possible nuclear accident.

In the case of grazed grass, only leaf transfer was studied, as this transfer pathway is predominant and urgent over root transfer over the first year following accidental release. Activity at time t after deposit, C, is thus determined by the initial contamination, taking into account the weather conditions on the day of deposit, plant growth (activity dilution), radioactive decay during the time period between deposit and grass consumption:

$$C = \frac{D}{Yld} \cdot \left[Kr \cdot RC_{dry} + (1 - Kr) \cdot RC_{wet} \right] \cdot k$$

and

$$k = a \cdot e^{-(\lambda_{bw} + \lambda_r) \cdot t} + (1 - a) \cdot e^{-(\lambda_L + \lambda_r) \cdot t}$$

where:

D : Total deposit on plant (Bq.m^{-2})

K_r : Dry deposit as a proportion of total deposit

Yld : Crop yield (kg$_{fresh}$.m^{-2}) at the deposit time

a : Decay weighting factor

t : Time elapsed since deposition (d)

RC_{dry}, RC_{wet} : Retention ratio in dry and rainy weather, respectively

λ_{bw}, λ_L, λ_r : Long term decay constants, due biological growth, leaf leaching and radioactive decay (d^{-1})

The Kr parameter indicates the proportion of dry deposit proportion within a given total deposit. It is likely to be a regionalised value as it varies according to rainfall intensity at the time of deposition. However, weather conditions prediction in accidental situation is impossible. In fact, it is a risk factor exclusively linked to the event. Therefore, for this study a value of Kr equals 1 (entirely dry deposit) or 0 (entirely wet deposit) was used in the ASTRAL simulations.

The retention ratio (also referred to as interception ratio) is the dimensionless ratio of activity taken up by vegetation and total activity deposited on 1 m^2 (Chamberlain, 1970). In the ASTRAL model, the retention value depends only on the surface area developed by plant coverage at the time of deposition, irrespective of the physiological state of the plant (photosynthetic activity, ageing etc.). It corresponds to the total deposited activity fraction intercepted by the above-ground part of the plants. The retention ratio, RC_{dry}, can be estimated on the basis of the leaf area index (defined as the surface area likely to collect aerosols, i.e., the leaf area per soil surface unit). All leaf areas, cumulated over the various plant growth stages, are taken into account, per soil surface unit (m^2 leaves/m^2 soil), irrespective of their photosynthetic activity. This definition is thus different from the agronomic definition where only green leaf surface area is considered. The German model, ECOSYS-87 (Müller and Pröhl, 1993), proposes a calculation mode, in dry weather conditions, for deposition on plant and total deposition; the ratio of the two values corresponds to retention. It makes the assumption that a radioactive deposit, on any surface area, is evaluated as the product of a deposition velocity by the radio nuclide concentration value in air and that deposition velocity on the plant depends on foliar development (LAI: Leaf Area Index). The variable chosen in order to characterize plant development stage is leaf area index and the following equation defines the retention ratio in dry weather:

$$RC_{dry} = \frac{LAI_i / LAI_{i\max}}{\left(LAI_i / LAI_{i\max}\right) + \left(Vg_s / Vg_{i\max}\right)}$$

where:

LAI_i : Leaf area index of plant I
LAI_{imax} : Maximum leaf area index of plant I
Vg_{imax} : Maximum deposit rate on plant I ($m.s^{-1}$)
Vg_s : Deposit rate on soil ($m.s^{-1}$), a constant for all plant types

In the case of deposit in rainy weather (cumulated rainfall over deposit period in excess of 1 mm, according to the ASTRAL model assumptions), the studies by Angeletti and Levi (1977), followed by those by Hoffman (1989) demonstrated that interception (represented by retention ratio in damp conditions, RC_{wet}, essentially correlates to the biomass, represented by the leaf area index (LAI) and to the contaminated rainfall:

$$RC_{wet} = \left(LAI \times \frac{S_2}{P}\right) \times \left[1 - 2^{-\left(\frac{P}{3S_2}\right)}\right]$$

where:

S_2 : Saturation coefficient (mm), dependent on the radio nuclide and the plant
P : Rainfall (mm)

The Yld parameter (above-ground biomass yield) corresponds to the mass of the plant in kg (fresh matter) per m^2 of soil at the time of harvest and more particularly, at the date of pasture grass ingestion by animals. This parameter meets the definition of agronomic yield, in as much as the edible part of the grass corresponds to the above-ground biomass. Since this agronomic parameter is highly variable from region to region: therefore, the yield is also likely to be regionalised.

Changes in the ^{137}Cs specific activity of the grass over the days following deposition are modelled by bi-compartmental exponential decay, where one parameter, λ_{bw}, governs short-term activity elimination (accounting mainly for grass growth) and the other, λ_L, rules long term elimination. This decay is attenuated after a certain time as the plant again taken up in plant stems. Parameter a, which is defined as a decay weighting factor, determines the activity fraction which was initially retained on other grass and which will decay over the course of time, in line with either of the two decay constants. This study does not look at the regionalisation of these three parameters (λ_{bw}, λ_L and a), since they will be taken at known values, determined based on experiments conducted in the scope of IRSN's TRAVAC programme (Réal and Roussel, 1995; Renaud *et al*., 1999a, b).

STICS, an agronomic software from INRA is a daily crop growth model (Brisson and Mary, 2002). Its input variables relate to climate, soil and technical management. Its output variables relate to production (quantity and quality), environment and changes soil characteristics under the influence of cultivation. STICS was designed as an operational simulation tool in agricultural conditions. Its main objective is to simulate the consequences of variations in environment and farming methods on the production from an agricultural plot, over the course of year. Crop growth is generally appraised through its above-ground biomass and nitrogen content, its leaf area index, as well as the number and biomass (and nitrogen content) of harvested organs. In the STICS model, the leaf area index meets the agronomic definition of leaf area index, considering only the cumulated surface area of green leaves per unit of soil area.

The soil is considered as a series of horizontal layers, each characterized by its water, mineral nitrogen and organic nitrogen reserves. Interactions between soil and crops occur via the roots, which are defined by a distribution of root density in the soil profile. The model simulates the system's carbon, water and nitrogen balances and allows the calculation both of agricultural variables (yield, fertilizer consumption) and environmental variables (water and nitrate loss) in various agricultural situations. The meadow's LAI value is hence assumed to vary from region to region, at any given date.

ASTRAL/STICS coupling: This study assumes that plant cover is not at same stage at any given time t, across the entire French territory. The ASTRAL model's radio ecological parameters -retention (RC_{dry} and RC_{wet}) and yield-change in accordance with the STICS model's agronomic parameter LAI. This enables the ASTRAL model's outputs (radioactive contamination of the grassland), to take regional diversity in cultivation conditions into account. The sources of variability considered apply to climate, soils and farming practice (fertilizer use, dates of grazing, duration of grazing per each plot).

Choice of farms: In order to study the influence of regional variability, we tried to define the simulation scenarios likely to illustrate the variability of the main dairy systems used in France, by classifying the farms according to information collected on the use of permanent grassland, in terms of animal feeding: forage rationing, feeding calendars, food supplement type and quantities of concentrates given, etc. Initially, a survey on the use of permanent grassland in France was used to provide case studies. The Institut de l'Elevage Français provides details of typical examples of farms and studies based on the agricultural statistical datas *Agreste* (Rabaut, 2000) provides complementary information on agricultural practices for grassland use throughout the dairy regions of France.

Test regions: Three regions were chosen to test the regional effect: Normandy, Lorraine and Rhone-Alps region. This selection was made on the basis of climate and topographical factors, the percentage of grassland, milk production and the number of cows in the region. The aim was to focus on regions, which firstly represent the climatic and topographical variations liable to lead to major productivity variations from region to region on a national scale and secondly, regions with large areas of permanent grassland. Plots used solely for grazing account for 57% of permanent meadows in Normandy, 43% in the Rhone-Alps region and 32% in Lorraine.

Farming models: Farming systems were selected in order to represent the dairy management diversity on the basis general data on agricultural practices and feeding calendars, in particular, grazing dates and nitrogen fertilizer use. Table 1 shows the data collected, as required for input into the STICS model for the three test regions. The information provided in the *Agreste* statistics compendium (Rabaud, 2000) and that provided by the Institut de l'Elevage gived us the parameters for STICS modelling (Table 2).

Table 1: Key dates and food intake for the dairy cows in the 3 areas (Institut de l'Elevage, personal communication) *and* (Rabaut, 2000)

Areas	Normandy	Lorraine	Rhone-Alps
Grazing initiation date	March-15	April-15	April-01
Total grazing period	April-15/October-01	May-01/September-15	April-15/October-15
Date of return to building for winter	October-15	October-15	November-01
Time spent by the cows on each plot	3 to 5 days	3 to 5 days	5 to 10 days
Period before return on the grassland:			
- Spring	2 to 4 weeks	2 to 4 weeks	3 to 5 weeks
- Beginning of summer	3 to 6 weeks	4 to 6 weeks	4 to 6 weeks
- End of summer	5 to 8 weeks	5 to 8 weeks	6 to 8 weeks

Table 2: Description of the technical parameters modified in the software STICS

	Value used for simulations					
Parameters	Normandy		Lorraine		Rhone-Alps	
Day of harvest stop	day 288-October-15		day 288-October-15		day 305-November-01	
Fertilization dates and nitrogen quantities applied to the plots (nnits per hectare)	day 80-March-21	55	day 74-March-15	50	day 74-March-15	25
	day 146-May-26	55	day 146-May-26	50	day 157-June-06	25
Grazing dates	day 74-March-15		day 105-April-15		day 91-April-01	
	day 105-April-15		day 140-May-20		day 125-May-05	
	day 140-May-20		day 160-Jnne-09		day 152-June-01	
	day 160-June-09		day 200-July-19		day 186 - July -05	
	day 200-July-19		day 240-August-28		day 236-August-24	
	day 240-August-28		-		day 300-October-27	

In Lorraine, these datas showed that herds are beginning the grazing period in spring with a mixed diet (supplements/grazing). From the end of April onwards, the cows are grazing night and day and are solely grass-fed, with no concentrates added. They spend some days in a plot, before being moved to other plot, using rotational grazing management. Grassland is divided into plots, which are grazed for a length of time that varies with the season, the grazing stocking rate and the growth conditions due to climate, soils and fertilization. During the summer, cows stay in one plot for 4 to 6 days. From mid-September onwards, cows grazed only during the day and they are returned to building for winter around the 15 October. These data were used to calculate the dates on which the cows move into and out of each plot, as shown in Table 1. Nitrogen fertilizer is applied twice, with 50 units per hectare in the first fortnight of March and 50 further units in the second fortnight of May or first fortnight of June.

In the Rhone-Alps region, the typical farm chosen was a hill farm (700 m altitude) in mountainous grassland regions in the foothills and mountains of the Northern Alps (Savoy, Haute-Savoie, Haut-Bugey, Monts du Forez and Pilat). A fully or predominantly grass-based fodder system was selected, with a large majority of permanent grassland (85 to 90%), rather than temporary meadows. Cows grazed early as possible, generally at the start of April, in order to avoid the flooding which can occur in the first few weeks of spring. A rotational grazing system is used, with similarly sized plots grazed night and day. On average, 5 to 7 plots are used in spring and twice as many in summer. Dairy cows are kept for 3 to 5 days or more in each plot (10 to 15 days during the summer). The grassland has to remain ungrazed in order for reserves to be formed-and the required time varies from season to season, with 3 to 5 weeks at the start of the season, 2 to 3 weeks in the growing season and 4 to 6 weeks during the summer and late season. However, the time allowed before cows return to the plots also depends on the number of plots accessible to dairy herds. Mineral nitrogen is used to fertilize meadows twice, in mid-March and at the start of June, with 25 units per hectare applied each time.

The size of the typical farm selected in Normandy is approximately 80 hectares, including 50 hectares of grassland and 9 hectares of maize for silage. The system considered is a mixed grass and maize system, with some hay. Rotational grazing is also used, involving 6 to 8 plots. On average, cows are kept for 3 to 5 days in each plot throughout the grazing season from 15th March to 15th October (Table 1). According to (Soltner, 2005), the recovery time of a meadow plot in North-Western France is 25 to 30 days in April, 14 to 18 in May, 20 to 25 in June and July, 35 to 45 from July to September and 50 to 60 from September to November. Grassland is intensively managed, with high levels of nitrogen fertilizer (110 units per hectare, applied twice, at the end of March and at the end of May).

Simulations performed with STICS: The program that can be downloaded from the INRA (French Institute for Agronomy Research, Avignon Centre) http://www.avignon.inra.fr/stics/, provides access to various input files, giving a database of main parameters for operating the model. Our study required some of these default values to be altered, in order to test several scenarios and to show regional variability. Physiological and agronomical data for each plant species represented in the model are summarized in the files plant.plt and technique.tec. The physiological features of fodder grass, in particular hardy meadow grass species such as fescue and orchard grass, are summarized in the file prairie.plt. We kept the default values given in this file, firstly because our study focuses on the production of multi-purpose permanent meadows and secondly, since good grassland has a flora comprising 65 to 75% grass (Soltner, 2005). Some values in the prairie.tec file on the technical use of the meadow were changed, on the basis of results from the (Institut de l'Elevage, 2005) and (Rabaut, 2000): no sowing date, no irrigation, latest harvest dates (irecbutoir) or latest grazing dates, set up to correspond with the return of cows to building for winter. Nitrogen fertilizer is applied to fertilised plots in two stages. Fertilizers are initially applied in March, to initiate growth for the meadow's first grazing. The second application generally follows the first grazing period, to boost grass regrowth in order to achieve an abundant fodder production. However, 16% of farmers in Normandy, 30% of farmers in Lorraine and 51% in the Rhone-Alps region never use fertilizer on their permanent grassland (Rabaut, 2000). Fertilizers may also be applied a third time in spring, if summer grazing is managed. For the purposes of the simulations, we considered that fertilizers are first applied in March, prior to initiate grazing in Lorraine and the Rhone-Alps region, but subsequent the first grazing period in Normandy, since cows began to graze earlier. We considered that the second fertilizer application was at the end of May in Normandy and Lorraine and at start of June on alpine pastures, due to the different cows grazing periods and dates. The dates and nitrogen quantities applied to the plots were thus changed in the technique.tec file in order to take into account regional practices. Grazing dates for each plot were thus calculated for each region on the basis of grazing dates, the grazing period in each plot and the recovery period, which varies according to the season and the number of plots available to the herd. According to regional data (Institut de l'Elevage, 2005), it is considered hat, depending on the region, dairy herds graze the same meadow plot 5 or 6 times.

Specific climate data for regional simulation are required on a daily basis. They should relate to one calendar year, with the year, month, day of the month, corresponding Julian day (from 1 to 365) and take into account minimum and maximum daily temperatures, total daily sunshine, evapotranspiration and daily precipitation. Data used in this study was taken from the weather stations considered the most representative for each region (Météo-France, 1996), i.e., Caen for Normandy, Metz for Lorraine and Bourg-St-Maurice for the Rhone-Alps region.

The STICS model default pedological file provides various soil type descriptions and the dataset sol-prairie (grassland soil) was used in simulations. The influence of soil type on Leaf Area Index (LAI) values and retention ratio was also studied, but proved to be negligible.

RESULTS

Radioactive retention ratio: The STICS simulations output LAI values for each day. Figure 1 shows the changes in LAI for each region. Falls in the LAI value are due to grazing. These falls are then followed by a leveling off, coinciding with the recovery periods, during which the meadow grows back, a period that is vital in determining yield. The various regional variation parameters considered (climate, soil, fertilizing practices, grazing dates) suggest that the changes in LAI are staggered by between one or four weeks from region to region. The earliest grazing takes place in Normandy, from 15th March onwards and the latest grazing is on 1st November, in the Rhone-Alps region. The STICS model shows that the LAI follows a fairly similar curve for all three regions, due to similar farming practices. The main difference in the curve is that the grazing dates and therefore growth cycles may be offset by up to a month or more between regions.

The equations mentioned above can be used to calculate changes in the retention ratio in dry wet weather (RC_{dry} and RC_{wet}) on the basis of changes in the leaf area

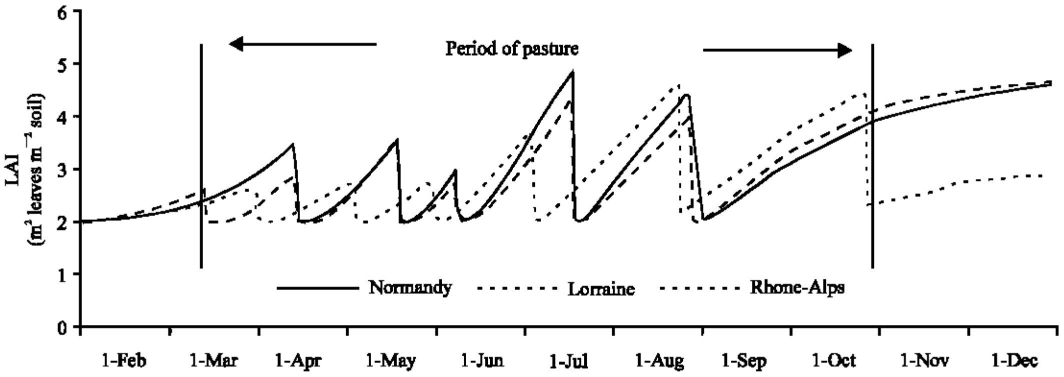

Fig. 1: Evolution of the Leaf Area Index according to areas

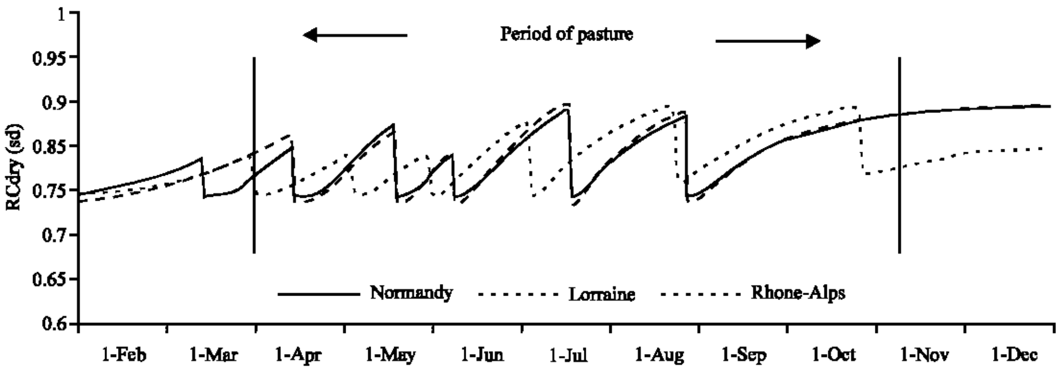

Fig. 2: Temporal evolution of the interception capacity in dry weather according to the areas

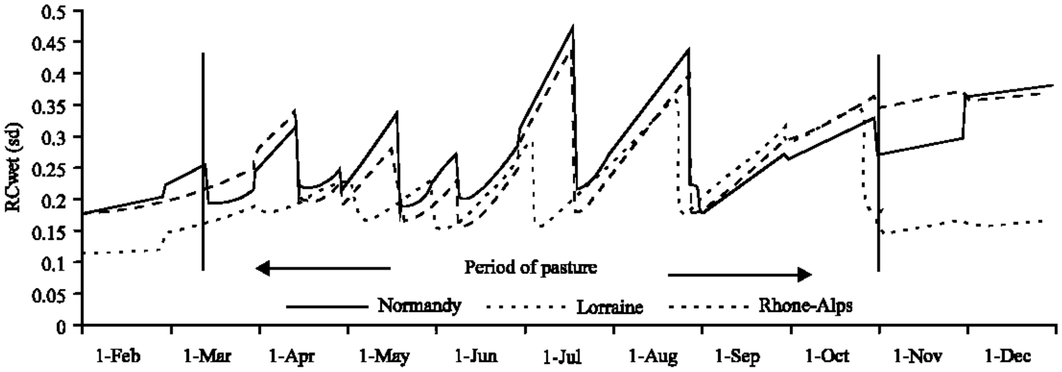

Fig. 3: Temporal evolution of the interception capacity in rainy weather according to the areas

index (Fig. 2 and 3). Figure 2 shows that changes in the retention ratios in dry weather are similar for the three areas, despite the time lag resulting from the different grazing dates from region to region. Throughout the grazing season, the retention ratio in dry weather (RC_{dry}) varies between 0.7 (minimum) and nearly 0.9 (maximum). The last values are fairly consistent with the value of the ratio RC_{dry} equals to 0.9 which was calculated according to Chamberlain (1970) with the framework of the IRSN's RESSAC program (Maubert *et al*., 1992) and with the value equals to 0.8 which was obtained following the experiments carried out on grassland with the framework of RADEMIC (Madoz-Escande and Santucci, 2004). The ratio RC_{dry} will never be zero, as there is always a residual value for LAI, since cows, unlike goats, do not heavy graze, meaning that above-ground biomass remains, even after 5 grazing days on the plot. Calculating the retention ratio (RC_{dry}) on the basis of the LAI, integrating the variability in farming methods, shows that the retention ratio in dry weather (RC_{dry}) can vary by approximately 30% between the regions studied. However, due to the small differences between values from the three regions, it isn't useful to regionalize values for retention ratio in dry weather (RC_{dry}) in the ASTRAL radio ecological model. However, regionalisation would, allow to take into account the differences, in growth cycle (roughly one month).

However, factors such as climate, farming practices and in particular, grassland uses, have a significant influence on the variability in radioactive retention in wet weather (RC_{wet}) values. The variability factor can be up to 4 between the Rhone-Alps region and Normandy for retention ratio in wet weather (RC_{wet}) at any given time t during the grazing season. The variability factor for regional precipitation can be up to 3 (between Normandy and Rhone-Alps regions) during the dairy cows grazing season. During heavy rainfall, as seen in the Rhone-Alps region, in particular and in mountainous climates in general, the retention ratio in wet weather (RC_{wet}) is lower, since the rain causes aerosols deposited on grassland to be leached into the soil. The retention ratio in wet weather can vary from 0.11 (minimum) for the Rhone-Alps region to 0.47 (maximum) for Normandy during the cows-grazing season. It appears more useful to regionalize values for retention ratio in wet weather than those for dry weather in the ASTRAL model. Therefore, regionalisation would enable the differences between growth cycles in various regions (for retention in dry weather) to be taken into account, along with differences in the extent of transfer to the grass.

Grazing date: The default grazing dates given in the ASTRAL model (March-15; May-01; September-15; November-01) do not take grazing practices fully into account-factors such as length of grazing period in each plot, recovery period, return dates and any mowing, since, in the model, these dates are set, spaced 3 to 5 months apart, depending on the season, despite the fact that grazing dates vary from region to region. Indeed, variability is high, with differences between a fortnight and one month in grazing initiation, leading to knock-on differences in the dates of subsequent phases of grassland use. This variability arises due to various interacting factors, such as grazing initiation date, times spent by the cows on each plot, recovery times, which vary from region to region and season to season and the number of plots used for grazing.

The ASTRAL model is based on dairy herd grazing freely all year long on large plots, which is actually fairly uncommon in France. Indeed, free grazing limits the productivity of permanent grassland and hence fails to optimize the effort and investment made by the farmer in improving grassland management. The ASTRAL model can also correspond to grazed grassland and mowed on the dates set up within said model. The dates set in ASTRAL for initiating grazing period and returning herd

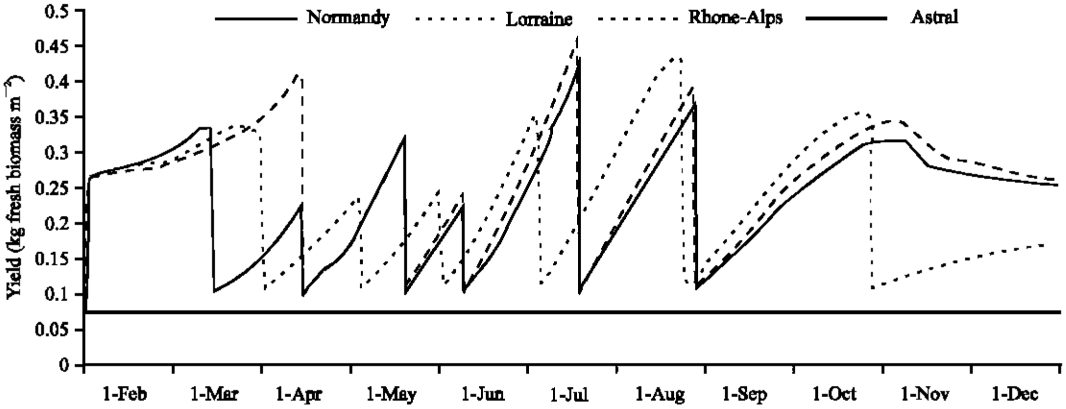

Fig. 4: Comparison of the values of yield between the ASTRAL model and the regional data resulting from the software STICS

Table 3: Yield of the grassland according to each reference

Area	Yield (kg fresh biomass m^{-2}) Survey	Stics	Astral
Normandy	3.50	2.31	0.70
Lorraine	3.25	2.58	
Rhone-Alps	2.00	2.20	

to building for winter are fairly consistent with normal practices in France, but the two intermediate dates do not particularly effectively take into account the variability in agricultural practices for permanent grassland in France.

Yield: In addition to the leaf area index (LAI) the STICS model output variable for above-ground organic matter, expressed in t ha^{-1} was studied, in order to quantify the yield for each region. Then, we compare this value with the generic value used by the ASTRAL model and data from statistical datas (Rabaut, 2000). Only one yield value is used for fodder grass throughout the year in the ASTRAL model: 0.7 kg$_{\text{fresh}}$ m^{-2} (Table 3). The regional values calculated using the STICS model correspond to the mean value for the simulation period (1st February to 1st November), rather than the whole year, unlike values given in the survey (Rabaut, 2000). The survey values are defined as the sum of two yields: firstly, grazing yield, estimated on the basis of the time spent by the cows on the plot each time round, the number of head present and the theoretical daily consumption of each animal category and secondly, added to the mowing yield, estimated for each mow. The high difference between the survey values and those calculated using the STICS model, particularly for Normandy and Lorraine, where the yield is higher than the Rhone-Alps, is therefore fairly logical. Figure 4 compares the regional yield values (in kg$_{\text{fresh}}$ m^{-2}) calculated in simulations using the STICS model and the generic value used by the ASTRAL model and shows that the variability factor between the ASTRAL model values, STICS model values and those given by the Institut de l'Elevage survey can be up to 5 or 6.

Direct transfer factor:

$$Ft_{wet} = RC_{wet} / Yield$$

and

$$Ft_{dry} = RC_{dry} / Yield$$

The ratios above give the direct transfer factors for dry weather and wet weather radioactive deposition respectively, taking into account retention, resuspension and translocation (Renaud *et al.*, 1997). The values shown in Fig. 5 were calculated on the basis of fresh matter yield for Normandy, Lorraine and the Rhone-Alps region at time t. The values used in the ASTRAL model for direct transfer factor in dry weather are 2 to 3 times higher than the values calculating using the STICS model, for the period 1st May to 15th September and 8 times greater for the period 1st November to 1st May. Likewise, the intensity of wet transfer, as calculated on the basis of the yield and LAI values from the STICS model is also between 4 and 10 times lower in the values given by the ASTRAL model between 1st November and 1st May and 2 to 2.7 times lower during the grazing season, from 1st May to 15th September. The main reason for the discrepancies found between the direct transfer values (Ft$_{dry}$) and (Ft$_{wet}$) is the difference between the yield values calculated with the STICS model and the default yield value used in the ASTRAL model.

If a yield of 0.7 kg$_{\text{fresh}}$ m^{-2} (default value in the ASTRAL model) is used to calculate direct transfer factors for each of the studied regions, taking into account the regional retention ratio values as calculated

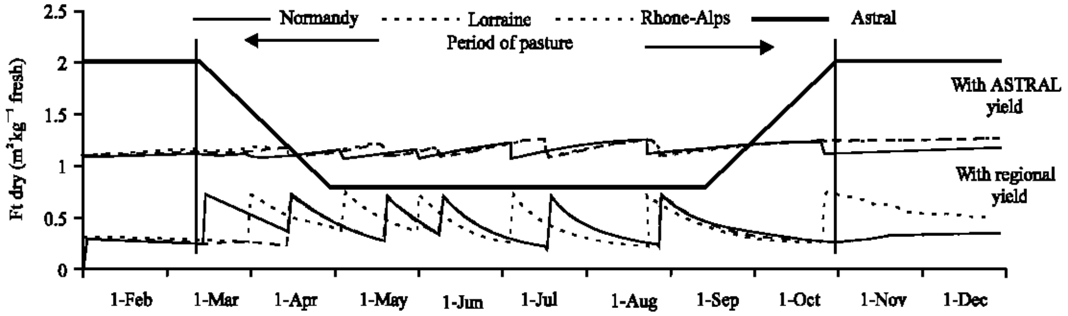

Fig. 5: Comparison of the value of Ft_{dry} according to ASTRAL and the regional data resulting from the software STICS

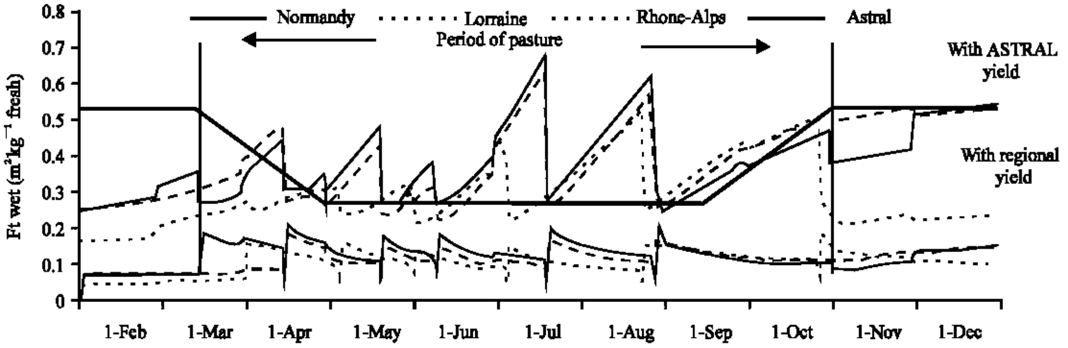

Fig. 6: Comparison of the value of Ft_{wet} according to ASTRAL and the regional data resulting from the software STICS

using the STICS model, the direct transfer factor in dry weather is very similar across the three regions, only varying between 1.1 and 1.2 (Fig. 5). This result highlights the trend mentioned above for retention in dry weather with no significant regional effect. Direct transfer factor values for deposition dry weather (Ft_{dry}) remain 1.5 times greater than the value used in the ASTRAL model, for all studied regions, over the period from 1st May to 1st November, when cows are exclusively grass-fed. A similar trend is found for the transfer factor with deposition in wet weather (Ft_{wet}) (Fig. 6). The direct transfer factor in wet weather in Normandy may be 2.5 times greater than the value used in the ASTRAL model. These results highlight the significance of regional yield values in studying grass contamination and changes to the generic grass yield value used in the ASTRAL model are to be recommended. Indeed, grazing period began when grass productivity is high and the yield value used should therefore be a maximum, rather than a mean yield.

Leaf contamination: In the simulations performed as part of this study, grass contamination is considered for a single grassland plot grazed by dairy cows 5 to 6 times during the grazing period, from 15th March to 1st November.

The deposition date and the time elapsed since deposition has a combined influence on the estimated specific activity in the grass. Thus, at any given time t, grass contamination arising from deposition at two different dates (1st February and 1st May) may therefore vary by factor of 1.5. This highlights the significance of the regional agricultural calendar and the purpose of analyzing variability between the regions.

Comparing deposition like-for-like, contamination in dry weather is always greater than in wet weather, by a factor of approximately 4. This does not contradict what was observed in France with fallout from the Chernobyl accident (Renaud *et al.*, 1999a, b). Indeed, deposition in rainy weather is higher and increases, in accordance with the intensity and length of rainfall, but, as was seen in the previous study on retention ratio in wet weather (RC_{wet}), there is limited radio nuclide retention in rainy weather, due to leaching from the leaves to the soil and to the fact that leaf transfer is lower.

CONCLUSIONS

This study assessed the effect of regionalizing various parameters in the ASTRAL radiological model for specific activity in fodder from a permanent meadow affected by accidental atmospheric radioactive deposition. This is a first step towards studying the sensitivity of the milk production industry to radioactive contamination via accidental pollution (the focus of the SENSIB project of IRSN). The main result of this study is to build a complementarily between a radio ecological model such as ASTRAL and an agronomical model such as STICS. Using these models in tandem enables ASTRAL's generic values to be compared with values given by STICS, which take into account various aspects of regional variability, such as climate, soil type and farmer practices. This is a genuine step forward in our understanding of the parameters used in the radioecology.

Now, more realistic values can be used as parameters in the ASTRAL radio ecological model, in order to assess the consequences of an accidental atmospheric radioactivity emission on permanent grassland. Using regionalised retention ratio values means that the time lag between plant growths cycles across the regions can be taken into account and, in the case of retention in wet weather, differences in the extent of plant transfer can be considered. Furthermore, comparing the transfer values calculated using the STICS model and the generic models from the ASTRAL model highlighted a difference with a factor of up to 3 for direct transfer (deposition in dry weather) and a factor of 10 in the event of direct transfer (deposition in wet weather). Studying the yield values showed the significance of this parameter in explaining these discrepancies and the vital importance of updating the generic value in the ASTRAL model. The IRSN is working hard to bring its radio ecological models up to date, by considering the most recent data on the management of permanent grassland and other farmer practices in France (Mignolet *et al.*, 2004). Managing the consequences of a radioactive pollution event will rely on a credible technical dialogue between research bodies and the agri-food industry and understanding farming practices is a basic building block for this dialogue.

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