The evolution of life expectancy since the beginning of the 20th century has meant that the rate of people becoming centenarians has increased considerably. This is confirmed by a recent report by Britain’s Department for Work and Pensions which refers to the probability of reaching the age of 100:

<table>
<thead>
<tr>
<th>Year</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>1931</td>
<td>5.1%</td>
<td>2.5%</td>
</tr>
<tr>
<td>1961</td>
<td>16.0%</td>
<td>10%</td>
</tr>
<tr>
<td>1991</td>
<td>26.5%</td>
<td>19.2%</td>
</tr>
<tr>
<td>2011</td>
<td>33.7%</td>
<td>26%</td>
</tr>
</tbody>
</table>

This study uses statistical and forecasting methods to analyse whether the longevity of centenarians is increasing and what impact this might have on the life annuity portfolios.
We can see that a child born today has an eight times greater probability of becoming a centenarian than eighty years ago. The British authorities estimate that, by the year 2066, the centenarian population will reach 500,000 inhabitants.

These figures will be surpassed if we take as a reference a study published in The Lancet magazine directed by Professor Kaare Christensen, of the Danish Ageing Research Centre, «in which, by analysing what has occurred in the past and what the trends have been, an extraordinary and constant pattern has been observed which shows that in the last 150 years there has been a very consistent increase in life expectancy in rich countries». It concludes: «If we project the current trends into the future, we can say that over 50% of babies born today in developed countries will live a 100 years».

If we look at the estimates of doctor and biophysicist, Roland Moreau, author of the book Immortality for tomorrow, which concludes that «by the year 2027 almost all of those born that year will reach the age of 100 and, if that is the case, some will reach 130, therefore exceeding the biological limit of 120 years achievable by the human being» and «if the genetic engineering therapies are materialised, altering the causes of ageing, the maxim limit for life could probably be exceeded». This opinion is in line with that of the scientist Ray Kurzweil, that, thanks to nanotechnology and a greater comprehension of how the human body works, vital organs will be able to be replaced and, in this way, live forever.

The object of this work is to ascertain the rates of survival for people who have become centenarians according to the different estimates from different models that attempt to evaluate longevity looking at the biology of the person associated with life styles. We can call these bioactuarial models.

At the same time, we will analyse the latest advances in biomedicine in relation to the causes that explain longevity and which will help us to understand if we are close, in time, to the possibility of increasing the maximum limit of probable life, which is commonly established at 120 years.

All of the above with the final objective being no other than to try to visualise if there is, or could be, a deficit in the technical reserves of the whole life portfolios for centenarian ages and, thus, substantiate Bertrand Russell’s aphorism «Do not feel absolutely certain of anything».

### Centenarians y supercentenarians

#### CENTENARIANS

The number of centenarians has grown considerably since the second half of the 20th Century, although this phenomenon will be a singularity of the present century. Taking US data according to Midrange estimate from Centenarians in the United States, U.S. Census Bureau of 1999, if in the year 2000 the centenarian population was 72,000 persons, by the year 2010 this figure will
reach 131,000 with a projection for 2050 that 834,000 North American citizens will be over 100 years old.

For the whole of the world population, in the period 2005–2050, a 35% growth in the population is estimated, whilst in the 100 years and over range, the growth will be 746%, which is the highest of all the age ranges, followed by the 85 to 99 age range which will grow 301%. This data is from the U.S. Census Bureau.

**SUPERCENTENARIANS**

A supercentenarian is someone who has reached the age of 110 years. From the registry of persons that have reached this age, it would appear that this ceiling is reserved for the feminine gender since, of those who reached 110 years, 90% were women, 92% reaching the age of 112 and 95% those who became supercentenarians, i.e. 115 years old.

This name is assigned to persons that have reached the age of 115 years according to the book *Supercentenarians*, coordinated by the Max Planck Institute for Democratic Research, in Rostock (Germany), and only nineteen people have reached this age since 1900, of which only two have been men. The book recalls the words written by Leonard Hayflick, one of the pioneers of modern research on ageing: «There is no evidence that the maximum duration of human life is different to some hundred thousand years ago. It is still around 115».

The longevity record still belongs to a French woman, Jeanne Calment, who is considered to have had the longest life. She died in 1997, when she was 122 years, five months and fourteen days and died on the 4th August, 1997, beating the previous unquestionable longevity record which belonged to Marta Graham, who lived for 114 years and 180 days, dying in 1958.

Since the registration of supercentenarians began, the oldest reference referred to Thomas Peter, who died in 1857 at the age of 111 and 354 days.

So, we can see from the official registers over 150 years that the longest life span on the planet has been increasing but it is also true that there is a biological limit on the maximum probable length life for human being which, traditionally, has been set at 120 years old.

In fact, it is significant that, if the number of human beings that have lived is calculated at 110,000 million, only one person has reached the age of 120 years.

One of the common characteristics among them is that they were not obese and had not smoked or had smoked very little.

Therefore, the frontier of 115 years represents an authentic biological barrier for the human being. In fact, in Japan, which is the country with the longest living people on the planet, and although the number of centenarians increased from 3,000 centenarians in 1992 reaching 40,000 in 2009, the oldest person in this period reached the age of 114.

This situation is continually repeated in several
Life style vs genetics for centenarians

The causes that determine longevity tend to attribute 25% to genetic factors and 75% to factors related to life styles, of which healthy nutritional and diet habits, physical exercise, social relationships and a positive attitude towards life stand out.

At the moment, there is an open debate between the scientific community that is expert in bio gerontology, those that consider that reaching the age of 100 years is a question of genes and those that feel, to the contrary, that life style is the principal cause for reaching extreme ages.

A recent article published in the Journal of the American Geriatrics Society concludes that genetics is the principle factor for becoming a centenarian. This study, directed by Nir Barzilai, Director of the Ageing Research Institute of the Medical Faculty of the Yeshiva Albert Einstein University (New York, USA), has been carried out by analysing the life style of 477 Ashkenazi Jews with ages of between 95 and 106 years and that lived independently.

The study is of a retrospective nature in that the participants were asked about their habits 30 years ago, i.e., when they were 70 years old. To evaluate the results, the data of a group of persons that have lived in the same era and that were around 70 years old participated in the NHANCES epidemiological study (National Health and Nutrition Examination Survey).

The conclusions of the report were that the body mass index and alcohol consumption were similar in both groups. Similar conclusions were reached when analysing physical exercise and diet.

Therefore, the study reveals that it is genetics that brings about extreme longevity.

It would seem reasonable to conclude that genes, environment, health habits and medical attention of the health system are the four factors that favour centenarian longevity.
In Spain there are 10,000 centenarians and two thirds of them are women. A study undertaken in Spain on the health of the centenarians describes some of their non-genetic characteristics:

- Half of them are independent, they do not need help to eat or carry out their daily activities.
- They live in a healthy environment.
- They live in an area that has a good medical attention health system.
- They have low cholesterol levels.

The debate remains open and, as biological knowledge of the centenarians advances, the effects of genetics and healthy life styles can be taken into account.

The survival rates of centenarians and supercentenarians

Having considered the foreseeable magnitude of the advent of a centenarian population in the next decades, we should reflect on how to model the risk of survival of this population which, up until now and for two reasons, did not acquire much relevance in the whole life portfolios of life insurance companies.

The first reason is that whole life portfolios insured in the Spanish market present a marked age concentration of around 70 years and, therefore, in general terms, only around 5% of today’s exposed risks will reach 100 years.

The second reason, which is related to the first since the insured portfolio is very distant from the centenarian risk exposure, is that there is practically no experience to evaluate the potential insufficiency of technical reserves and, if there were, the probability flows of these potential ages, discounted to the calculation date of the mathematical reserves, may not be significant today.

In no way should these arguments prevent the insurer from trying to model the risk of survival of the centenarian population in the light of the facts shown by the behaviour of this group in registers such as the Los Angeles GRG (Gerontology Research Group) in the USA and which will enable us to construct mortality trends that differ significantly from those incorporated in the survival tables of countries in general and which are based on a mortality trend that follows the Gompertz model, i.e., mortality grows exponentially with age.

The survival model constructed from the data observed by the GRG, which we would recall
corresponds to the official census registry data of each country that participated in the work group, reflects the evolution of the supercentenarian population. All in the knowledge, as said, in the actual group, having such little data, it might not have any statistical significance.

As Professor Steve Cole, Director of supercentenarian Research Foundation UCLA Molecular Biology Institute, asks:

«The real question is… do these cases represent a statistical aberration or is there a biological basis in the human genome for these atypical values?

If there is a biological basis for this plateau, ¿Can the phenotype of ageing be conquered by ordinary people?

Could there be a peculiar genetic predisposition to end up being Supercentenarians as from 114, ending at 117 years, in such a way that we should look at the ADN sequence?

¿Can the genes that determine longevity be discovered and manipulated by genetic engineering?»

Advancing us the conclusions, the proposed longevity model signifies in words of Dr. Fahy, Director of the Organ Cryopreservation Laboratory at the American Red Cross Jerome Holland Laboratory in Rockville: «The existence of a belated mortality plateau of life for human beings and other species implies that ageing above a certain age is detained».

Therefore, we have reproduced the main tables prepared from the available data. They were taken from www.grg.org.

The analysis commences with the observations of the supercentenarians incorporated in the North American Social Security tables for 2007 and we can see how it follows a completely different behaviour to that proposed by the table.

<table>
<thead>
<tr>
<th>Age</th>
<th>Number living</th>
<th>Decrease to next age</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>28,679</td>
<td>12,467</td>
</tr>
<tr>
<td>101</td>
<td>16,212</td>
<td>6,657</td>
</tr>
<tr>
<td>102</td>
<td>9,555</td>
<td>4,158</td>
</tr>
<tr>
<td>103</td>
<td>5,397</td>
<td>2,413</td>
</tr>
<tr>
<td>104</td>
<td>2,984</td>
<td>1,541</td>
</tr>
<tr>
<td>105</td>
<td>1,443</td>
<td>787</td>
</tr>
<tr>
<td>106</td>
<td>656</td>
<td>295</td>
</tr>
<tr>
<td>107</td>
<td>361</td>
<td>184</td>
</tr>
<tr>
<td>108</td>
<td>177</td>
<td>111</td>
</tr>
<tr>
<td>109</td>
<td>66</td>
<td>?</td>
</tr>
</tbody>
</table>

The register of the evolution of centenarians was taken from the following table.


Plot produced by Donald B. Gennery, March 11, 2008
And with regard to the Supercentenarians, the evolution was taken from:


<table>
<thead>
<tr>
<th>Age</th>
<th>Number at this age or higher</th>
<th>Number at this age by years</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>679</td>
<td>427</td>
</tr>
<tr>
<td>111</td>
<td>491</td>
<td>225</td>
</tr>
<tr>
<td>112</td>
<td>266</td>
<td>129</td>
</tr>
<tr>
<td>113</td>
<td>137</td>
<td>74</td>
</tr>
<tr>
<td>114</td>
<td>63</td>
<td>41</td>
</tr>
<tr>
<td>115</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>116</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>117</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>118</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>119</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>120</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>121</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>122</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>123</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

It can be seen that the annual death rate remains constant and is around 50% every year.

Subsequently, it is a question of modelling the behaviour of this population, as can be seen in the following graph.

**THE INSURER SHOULD TRY TO MODEL THE RISK OF SURVIVAL OF THE CENTENARIAN POPULATION IN THE LIGHT OF THE FACTS SHOWN BY THE BEHAVIOUR OF THIS GROUP IN REGISTERS SUCH AS THE LOS ANGELES GERONTOLOGY RESEARCH GROUP**
(according to Robert Young – founding member of the Supercentenarian Research Foundation – the USA Social Security data is probably not reliable for over 95 years) and as from that age a manual adjustment is made which, combining the table and model, is the result proposed by Donald B. Gennery in «Mortality rate as a function of age» (19-1-2010).

For the adjustment of the 90 years ages, the data tracking 290 persons that had reached the age of 90 years between 1920-1922 was used and the year in which they died was registered. The last one died at the age of 102 years.

This model proposed for extreme ages and taking as a basis the aforementioned social security table in which data for up to 90 years of age is used.
This proposed model of longevity behaviour of the general population, based on the experience of the supercentenarians, enables the extraction of some additional conclusions to the most relevant which is the existence of a mortality plateau on reaching 110 years. These conclusions are from Donald B. Gennery himself: “According to the above table, the probability of reaching this age is 2.11 x 10^9. From an estimation of 300 million births, the expected number of those born today that would reach the age of 122 years would be 0.6333 persons and applying a corrective factor of 5.41 for the current and past mortality differences produces an approximate expected number today of 0.117 of persons that should be 122 years old taking into account the highest mortality rates in the past”.

The modelling of centenarian ages taking the form of a plateau is a proposal that we can find in more recent actuarial literature via the bioactuarial and non observable heterogeneity models.

With regard to the first, we would quote the studies of Gavrilov & Gavrilova in Handbook of the Biology of Aging, Academic Press, 2006, where, starting with the theory of the reliability of the systems, they conclude that the risk of error is not necessarily related to age and that it can even be irrelevant. And, on observing the biological behaviour of certain living beings through longitudinal studies, they conclude that in the last stage of maximum probable life there is a deceleration in the increase of the mortality rates, reaching a plateau at a certain age; that is to say that the mortality rate remains constant. Gavrilov calls this process “kinetic mortality, since there is no biological wearing of the human being”.

As we commented previously, for this singular behaviour of extreme ages, the Gompertz, or even Weibull, models do not adequately reproduce living being reliability models which, in the case of human beings, can be verified with the behaviour of the evolution of the Swedish population Mortality of Swedish women for the period of 1990-2000 from the Kannisto-Thatcher Database on Old Age Mortality, and from the source Gavrilov-Gavrilova Why we fall apart. Engineering’s reliability theory explains human aging. (IEEE Spectrum, 2004)

We can see that, as from the age of 90, the survival curve is greater according to the Swedish experience than the proposals from the Gompertz models.
This hypothesis presents a challenge to the hypothesis that the biological limit of the human being is 120 years since the model leads us to propose the contrary, i.e., that the mortality rate in extreme ages, as it is constant, means that survival has no limit at any specific age. This proposal has many similarities with the conclusion of the model described and elaborated on the experience of supercentenarians.

The line of work based on non-observable heterogeneity models proposed by Olivieri and Pittaco, amongst other renowned actuarial researchers, suggests incorporating the fragility variable into the traditional mortality table. That is, the survival of an individual is affected by his propensity to longevity, which is a variable related to the individual phonotypical strengths that make individuals that survive to very advanced ages have survival rates that tend to take a plateau shape.

The origin of these models can be found in observations of old age mortalities in developed countries in which a deceleration has been observed in the growth rate of mortality for said ages, Horiuchi & Wilmoth (1998), Zen yi & Vaupel (2003).

In Antonio Fernández Morales’ work (2009), Graduation of mortality in Andalucía with mortality models with non-observable heterogeneity, published in the IAE Annals, he refers us to fragility (Zx) variable modelling where individuals with greater probability of death show lower rates of fragility. Gamma or Inverse Gaussian distributions are models, creating a mortality mixture function (Gompertz, Makeham) – fragility (Gamma or Inverted Gaussian distribution).

We can observe that from three different approximations, i.e. register of supercentenarians, bioactuarial and non-observable heterogeneity models, actuarial science is capable of reproducing the behaviour of the longevity of centenarians.

We know, therefore, that for these ages there is a plateau in the mortality rates and, as a result, the actuarial models should be corrected and adjusted to this trend which begins to be quantifiable to the extent that the longevity registers of these ages start to provide consistent data and can substitute mere projection estimates generated from mortality rates of younger ages.

Therefore, based on this knowledge acquired and modelled, it is advisable that companies review their levels of liabilities. Olivieri (2006) says: “To not consider heterogeneity due to non-observable factors in a life portfolio leads to an underestimation
of liabilities, both in the expected value as well as the right hand tail, since the mortality distribution in a heterogeneous population is different to that belonging to a homogeneous group, especially in the more advanced ages.

Knowing that we are faced with a new actuarial model which modifies the central hypothesis of biometrics based on the Gompertz (1820) model, current science has to be capable of proposing the age at which mortality starts to decelerate. All research leads us to propose the range of 90–95 and, on the other hand, evaluate the intensity of the plateau.

With this state of affairs, perhaps the best solution is to accept that this new phenomenon exists and to revise the underestimation of liabilities in the right hand tail of insureds, to adjust reserves as and when the models adapt to known statistical realities and, in the cases of the centenarian population, we should consult international population register sources.

Fenotypical longevity models

Having analysed the response of actuarial science to the phenomenon of longevity in persons of advanced age and, specifically, in centenarians, we will refer to the longevity study from the viewpoint provided by evolutive biodemography that attempts to combine the ageing theories of free radicals and perishable soma. Consider, therefore, that the longevity process is the result of the impulse of the acquisition of energy and its location.

The study Evaluation of mortality trajectories in evolutionary biodemography, of Stephan B. Munch, and Marc Mangel PNAS, published online Oct 23, 2006, provides us with a different viewpoint for understanding longevity and its repercussion on extreme ages.

The phenotype model shows us that the mortality trajectories are comprised of two variables depending on the phenotype: one depending on size and the other on damage. For its measurement, specific parameters are taken such as basal metabolism in variable foods in which the individuals regulate growth, the accumulation of damage and the depredation of the risk. All the parameters are assigned with a mechanistic interpretation.
As phenotype knowledge advances with deeper biomarkers, this model will provide us with the necessary metrics to understand the phenomenon of extreme longevity.

Continuing with this biomedical argument, we can go a step deeper in the knowledge of MLSP (Maximum Life Span Potential), which represents the maximum number of years for which an individual can live belonging to a specific species.

The maximum life span is determined by the genome which is constant and characteristic for each species. Maximum longevity correlates with resistance to general ageing processes and is inversely proportional to the maximum ageing speed of the species (Cutler, 1984).

The two biogenetic theories related to ageing are the theories of free radicals and shortening telomeres.

There are numerous studies that show that there is a relationship between free radicals and maximum life span.

José Gómez Sánchez’ analysis in his Doctoral Thesis (2010 UCM –Faculty of Biology), helps us to understand this process and says that the free radicals production rate correlates inversely to the maximum life span of the species, so that this rate is greater in species with a short life span than those with a long life span. (Barja et al., 1994b; Lambert et al., 2007; Robert et al., 2007).

It is on this point where we can introduce aspects of life styles such as diet restrictions related to longevity. Numerous researches have demonstrated that diet restriction is capable of reducing the mitochondrial production of free radicals (Sohal et al., 1994; Sohal & Weindruch, 1996; Gredilla et al., 2001a,b; Barja, 2002a; Drew et al., 2003; Bevilacqua et al., 2004; Judge et al., 2004; Gredilla & Barja, 2005).

The theory of shortening telomeres

All of the ageing tests start with the science of telomeres and telomerase, the enzyme which controls the cell’s biological clock. In fact, Jerry Shay of the Southwestern Medical Center in Dallas, in an article published recently in Science, tell us that «it is the best biomarker of ageing available today». In the same way...
as with the free radicals theory, a healthy life style is possible to have longer telomeres again.

It is still not possible to measure a person’s life expectancy with the size of the telomere but it is possible to know the biological age of someone in relation to their chronological age and, as the number of telomere analysis increase, relationships can be established between the life style and the biological clock. It has shown, in fact, that obesity and tobacco addiction involve an accelerated loss in telomeres.

These two biomedical theories that try to explain longevity were not interrelated, although Ronald A. DePinho, M.D. Dana-Farber Cancer Institute, affiliated to Harvard, in a publication in *Nature* in July, 2011, suggests that the shortening of telomeres is the cause mitochondrial dysfunction and of the reduction of antioxidant defences. Jointly, they reduce corporal energy and lessen the working of organs, two characteristics of ageing and, he continues, «What we have discovered is the main road to ageing that connects various different biological processes with age and that previously were considered to be independent from one another».

The relationship between the two theories will provide significant advances, particularly, in the knowledge and metrics of longevity of centenarians, knowing, as Heraclitus, said «Nature loves to hide itself».

Therefore, in years to come, biomedical science will be in a position to evaluate, from genetics and lifestyles, the probability of reaching centenarian and, eventually, supercentenarian ages.

Although actuarial science is starting to incorporate the knowledge acquired from biomedicine, it should go deeper along these lines in order to be able to model the risk of longevity. At the same time, it should evaluate the possibility of the extension of the maximum probable life where life expectancy is close to this indicator, and as one intellectual says, «Growing old is inevitable, the fight against the biological tendency of our genes to grow old has gone from impossible to infinitely unlikely».

In a dynamic demographic structure where centenarians will be the truly new protagonists, the whole life portfolios will involve extreme ages which are an undiscovered territory for insurers. The big advantage is that it is possible to start preparing strategies for periodic adjustment to assigned contingent liabilities in the balance sheet.