ProSINTAP - A Probabilistic Program for Safety Evaluation

Peter Dillström

SAQ / SINTAP / 09

SAQ KONTROLL AB

Box 49306, 100 29 STOCKHOLM, Sweden

Tel: +46 8 617 40 00; Fax: +46 8 651 70 43

ABSTRACT

Within SINTAP, Sub-Task 3.5, a probabilistic procedure has been developed by SAQ Kontroll AB to calculate two different failure probabilities, P_F:

- Probability of failure, defect size given by NDT/NDE.
- Probability of failure, defect not detected by NDT/NDE.

Using the procedure, SAQ Kontroll AB has also developed a computer program ProSINTAP. This program can also be used to estimate partial safety factors, given an input target failure probability and characteristic values for fracture toughness, yield strength, tensile strength and defect depth.

Extensive validation has been carried out, using the computer programs STAR6 from Nuclear Electric and SACC from SAQ Kontroll AB.

TABLE OF CONTENTS

NOMENCLATURE

a	Defect depth
$f(a)$	Defect depth, defect size - probability density function
$f(K_I)$	Fracture toughness - probability density function
f_{R6}	R6 function
$f_X(x)$	Joint probability density function
$F_X(x)$	Cumulative distribution function
$g(X)$	Limit state function
$g_{Linear}(u)$	Transformed limit state function, using a linear approximation
$g_{L_r^{max}}(X)$	L_r^{max} - limit state function
$g_{Quadratic}(u)$	Transformed limit state function, using a quadratic approximation
$g_{R6}(X)$	R6 - limit state function
$g_U(u)$	Limit state function in a transformed standard normal space U
k	Weibull distribution parameter - shape
K_I	Stress intensity factor
K_{Ic}	Fracture toughness
K_r	Fracture parameter
L_r	Limit load parameter
L_r^{max}	Upper limit of L_r
N	Total number of simulations
N_F	Number of failures during simulation
P_F	Probability of failure
$P_{F,FORM}$	Probability of failure, using First-Order Reliability Method
$P_{F,MCS}$	Probability of failure, using Simple Monte Carlo Simulation
$P_{F,SORM}$	Probability of failure, using Second-Order Reliability Method
t	Parameter used in the definition of the gamma function
u	Random number - between 0 and 1, transformed random parameter
U	Transformed random vector
x	Random parameter, random variable
X	Random vector
z	Parameter of the gamma function
β_{HL}	Reliability index
$\Phi(u)$	Cumulative distribution function in standard normal space
$\Gamma(z)$	Gamma function
κ_i	Principal curvatures of the limit state surface
λ	Exponential distribution parameter

μ_a	Defect depth, defect size - mean value
$\mu_{K_{Ic}}$	Fracture toughness - mean value
μ_{LogNor}	Log-normal distribution parameter - log-normal mean value
θ	Weibull distribution parameter - scale
ρ	Parameter for interaction between primary and secondary stresses
σ_a	Defect depth, defect size - standard deviation
$\sigma_{K_{Ic}}$	Fracture toughness - standard deviation
σ_{LogNor}	Log-normal distribution parameter - log-normal standard deviation
σ_U	Ultimate tensile strength
σ_Y	Yield strength

1. INTRODUCTION

Within SINTAP, Sub-Task 3.5, a probabilistic procedure has been developed by SAQ Kontroll AB to calculate two different failure probabilities, P_F:

- Probability of failure, defect size given by NDT/NDE.
- Probability of failure, defect not detected by NDT/NDE.

Using the procedure, SAQ Kontroll AB has also developed a computer program ProSINTAP. It consists of two separate parts:

- An user interface program ProSINTAP, written using Visual Basic 5.
- A solver program ProSolvr, written using Digital Visual Fortran 5.

ProSINTAP is intended for use on Microsoft Windows 95 / 98 / NT. Using and interpreting the results and its consequences are always the responsibility of the user and SAQ Kontroll AB takes no responsibility on how the program is used or for any consequences due to possible errors in the program. Any found errors, suspicious results, program failure or misbehaviour of any kind should be brought to our attention immediately.

1.1 Installation

Before you can run ProSINTAP, you must first install it by running the Setup Program on the CD. It will install all the necessary files to run ProSINTAP.

1.2 Help and Technical support

A help system is included within ProSINTAP. If one need more extensive technical support, please send an E-mail with a detailed description of the problem together with information on what versions of ProSINTAP and operating system are being used to the E-mail address peter.dillstrom@saq.se.

Bug lists, upgrades or other vital information on the use of ProSINTAP will be distributed to registered users with E-mail.

2. USING ProSINTAP

2.1 Running interactively or in batch

One can run ProSINTAP, either interactively or as a batch program.

2.1.1 ProSINTAP, interactive version

This is straightforward, just start ProSINTAP from the Windows start menu. Then one has the two choices:

- Start a new job.
- Open an existing job.

2.1.1 ProSINTAP, batch version

To run the batch version of ProSINTAP, one has to execute the solver ProSolvr.exe with a job name as parameter. The program will then use a file with the extension inp as input data. Below is an example using the job name test23 (input file test23.inp):

```
ProSolvr  test23
```

2.2 Files used within the ProSINTAP program

The user interface program ProSINTAP communicates with the solver program ProSolvr using text files. The following files are used (all with the example job name my_test_job):

- my_test_job.pro — Job file used by ProSINTAP, must be present to run a job using the user interface program.
- my_test_job.inp — Input file to the solver program ProSolvr, either generated by the user interface program or modified by a text editor.
- my_test_job.res — Results file from the solver program ProSolvr, input to the user interface program.
- my_test_job.log — Log file from the solver program ProSolvr, gives more information than the results file. This file is also input to the use interface program.

The relationship among the different files and programs can also be found in figure 2.1.

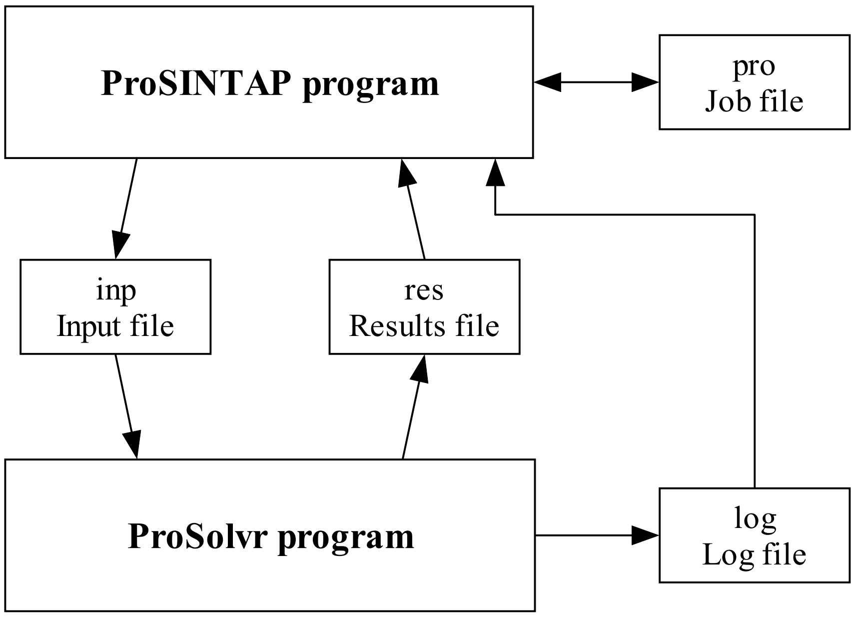

Figure 2.1. The relationship among the different files and programs.

2.3 ProSINTAP, input data

The input data to ProSINTAP is divided into five input tabs, Geometry, Loads, Material, NDT/NDE and Analysis. A short description follows:

2.3.1 Geometry

When calculating probability of failure, defect size given by NDT/NDE, only data for the component / crack type need to be given. When calculating probability of failure, defect not detected by NDT/NDE, one also has to include data for a defect depth distribution.

Input data for component / crack type:

- A plate with an infinite surface defect as defined in STAR6.
  - Plate thickness
- A plate with a finite surface defect.
  - Defect length to depth ratio
  - Plate thickness
- A plate with an infinite surface defect.
  - Plate thickness

- A plate with a through-thickness defect.
  - Plate thickness
- A cylinder with a finite axial internal surface defect.
  - Defect length to depth ratio
  - Wall thickness
  - Internal radius
- A cylinder with a part circumferential internal surface defect.
  - Defect length to depth ratio
  - Wall thickness
  - Internal radius
- A cylinder with a circumferential through-thickness defect.
  - Wall thickness
  - Internal radius

Input data for defect depth distribution:

- A normal distribution.
  - Mean and standard deviation
- A log-normal distribution.
  - Mean and standard deviation
- An exponential distribution.
  - Mean
- A Marshall distribution.
  - No data needed

2.3.2 Loads

For all the geometry's in 2.3.1, a through thickness, primary and secondary stress distribution must be defined (using two to ten values). ProSINTAP then calculates equivalent membrane and bending stresses.

For the cylindrical geometry's with circumferential defects, primary and secondary global bending stresses must also be given as input data.

2.3.3 Material

Input data for fracture toughness, yield strength and tensile strength must be given. All may follow a normal, log-normal or a Weibull distribution, defined by giving a mean value and value for the standard deviation.

2.3.4 NDT/NDE

When calculating probability of failure, defect size given by NDT/NDE, data for sizing probability need to be given. This may follow a normal, log-normal or an exponential distribution.

When calculating probability of failure, defect not detected by NDT/NDE, data for detection probability need to be given (a value between 0 and 1). This is treated deterministically in this release of ProSINTAP.

2.3.5 Analysis

One also has to choose a method to calculate the failure probabilities. Input data are:

- First-Order Reliability Method (FORM).
  - No data needed

- Simple Monte Carlo Simulation (MCS).
  - Number of samples.

If wanted, ProSINTAP can also estimate partial safety factors (using FORM), given an input target failure probability and characteristic values for fracture toughness, yield strength, tensile strength and defect depth.

2.4 ProSINTAP, results

The results from ProSINTAP is divided into two results tabs, Summary and Solver log. The type of results presented are dependent of the method chosen to calculate the failure probabilities. A short description follows:

2.4.1 Summary

- Using First-Order Reliability Method (FORM).
  - The probability of failure.
  - The reliability index.
- Using Simple Monte Carlo Simulation (MCS).
  - The probability of failure.
  - Error with 95% confidence.

2.4.2 Solver log

- Using First-Order Reliability Method (FORM).
  - Input data.
  - The most probable point of failure in original space.
  - The most probable point of failure in normalised space.
  - Sensitivity factors.
  - Partial safety factors.
  - The probability of failure.
  - The reliability index.
- Using Simple Monte Carlo Simulation (MCS).
  - Input data.
  - The probability of failure.
  - Error with 95% confidence.

3. THEORY

3.1 Failure probabilities

Within SINTAP, Sub-Task 3.5, a probabilistic procedure has been developed to calculate two different failure probabilities, P_F:

- Probability of failure, defect size given by NDT/NDE.
- Probability of failure, defect not detected by NDT/NDE.

The procedure uses two different limit state functions, $g(X)$:

$$g_{R6}(X) = g_{R6}(K_{Ic}, \sigma_Y, a) = f_{R6} - K_r \tag{3.1}$$

$$g_{L_r^{\max}}(X) = g_{L_r^{\max}}(\sigma_Y, \sigma_U, a) = L_r^{\max} - L_r \tag{3.2}$$

These limit state functions are based on the SINTAP ‘Known YS - Known UTS’ FAD only (Level 1). Then, to calculate the probability of failure, a multi-dimensional integral has to be evaluated:

$$P_F = \Pr\left[g(X) < 0\right] = \int_{g(X)<0} f_X(x)dx \tag{3.3}$$

$f_X(x)$ is a known joint probability density function of the random vector X. This integral is very hard (impossible) to evaluate, by numerical integration, if there are many random parameters.

3.2 Parameters

Within the chosen procedure, the following parameters are treated as random parameters:

- Fracture toughness
- Yield strength
- Ultimate tensile strength
- Defect size given by NDT/NDE
- Defect not detected by NDT/NDE
- Defect distribution

These random parameters are treated as not being correlated with one another. The parameters can follow a normal, log-normal, Weibull or some special distributions (for the defects).

3.2.1 Fracture toughness

The fracture toughness can follow a normal, log-normal or Weibull distribution.

The normal probability density function has the following form:

$$f(K_I) = \frac{1}{\sigma_{K_{Ic}} \cdot \sqrt{2 \cdot \pi}} \exp\left(-\frac{1}{2} \cdot \left[\frac{K_I - \mu_{K_{Ic}}}{\sigma_{K_{Ic}}} \right]^2 \right) \tag{3.4}$$

where $\mu_{K_{Ic}}$ (mean) and $\sigma_{K_{Ic}}$ (standard deviation) are input data to ProSINTAP.

The log-normal probability density function has the following form:

$$f(K_I) = \frac{1}{K_I \cdot \sigma_{LogNor} \cdot \sqrt{2 \cdot \pi}} \exp\left(-\frac{1}{2} \cdot \left[\frac{\ln(K_I) - \mu_{LogNor}}{\sigma_{LogNor}} \right]^2 \right) \tag{3.5}$$

where μ_{LogNor} and σ_{LogNor} are the log-normal distribution parameters. $\mu_{K_{Ic}}$ (mean) and $\sigma_{K_{ic}}$ (standard deviation) are input data to ProSINTAP and are related to the log-normal distribution parameters as follow:

$$\mu_{LogNor} = \ln\left(\mu_{K_{Ic}}\right) - \frac{1}{2} \cdot \left(\sigma_{LogNor}\right)^2 \tag{3.6}$$

$$\sigma_{LogNor} = \sqrt{\ln\left[1 + \left(\frac{\sigma_{K_{Ic}}}{\mu_{K_{Ic}}}\right)\right]} \tag{3.7}$$

The Weibull probability density function has the following form:

$$f(K_I) = \frac{k}{\theta} \cdot \left(\frac{K_I}{\theta}\right)^{k-1} \cdot \exp\left(-\left(\frac{K_I}{\theta}\right)^k \right) \tag{3.8}$$

where θ (scale) and k (shape) are the Weibull distribution parameters. $\mu_{K_{Ic}}$ (mean) and $\sigma_{K_{ic}}$ (standard deviation) are input data to ProSINTAP and are related to the Weibull distribution parameters as follow:

$$\mu_{K_{Ic}} = \frac{\theta}{k} \cdot \Gamma\left(\frac{1}{k}\right) \tag{3.9}$$

$$\sigma_{K_{Ic}} = \sqrt{\frac{\theta^2}{k} \cdot \left[2 \cdot \Gamma\left(\frac{2}{k}\right) - \frac{1}{k} \cdot \Gamma\left(\frac{1}{k}\right)^2\right]} \tag{3.10}$$

where Γ(*z*) is the gamma function, defined by the integral

$$\Gamma(z) = \int_0^\infty t^{z-1} \cdot e^{-t} dt \tag{3.11}$$

This non-linear systems of equations are solved using a globally convergent method with line search and an approximate Jacobian matrix.

3.2.2 Yield strength and Ultimate tensile strength

The Yield strength and the Ultimate tensile strength can follow a normal, log-normal or Weibull distribution. For information regarding input data and distribution parameters, see chapter 3.2.1 above.

3.2.3 Defect size given by NDT/NDE

The defect size given by NDT/NDE can follow a normal, log-normal or exponential distribution. For information regarding input data and distribution parameters, using a normal or log-normal distribution, see chapter 3.2.1 above.

The exponential probability density function has the following form:

$$f(a) = \lambda \cdot \exp(-\lambda \cdot a) \tag{3.12}$$

where λ is the exponential distribution parameter. μ_a (mean) is input data to ProSINTAP (equal to the standard deviation, σ_a, for this distribution) and is related to λ as follows:

$$\mu_a = \sigma_a = \frac{1}{\lambda} \tag{3.13}$$

3.2.4 Defect not detected by NDT/NDE

The parameter defect not detected by NDT/NDE are treated as a deterministic parameter in this release of ProSINTAP.

3.2.5 Defect distribution

The defects can follow a normal, log-normal, exponential or Marshall distribution. For information regarding input data and distribution parameters, see chapters 3.2.1 and 3.2.3 above.

The Marshall distribution is a special case of a more general exponential probability density function. It has the following form:

$$f(a) = 0.583 \cdot \exp(-0.16 \cdot a) \tag{3.14}$$

3.3 Calculation of failure probabilities

As mentioned above, the failure probability integral is very hard to evaluate using numerical integration. Instead, the following numerical algorithms are included within the procedure:

- Simple Monte Carlo Simulation (MCS)
- First-Order Reliability Method (FORM)

3.3.1 Simple Monte Carlo Simulation (MCS)

MCS is a simple method that uses the fact that the failure probability integral can be interpreted as a mean value in a stochastic experiment. An estimate is therefore given by averaging a suitably large number of independent outcomes (simulations) of this experiment.

The basic building block of this sampling is the generation of random numbers from an uniform distribution (between 0 and 1). Simple algorithms ”repeats itself” (already) after approximately $2 \cdot 10^3$ to $2 \cdot 10^9$ simulations and are therefore not suitable to calculate medium to small failure probabilities. The algorithm chosen for ProSINTAP repeats itself after approx. $2 \cdot 10^{18}$ simulations (this algorithm is approximately 20 times slower than the simpler algorithms mentioned above, but it is recommended if one needs more than $1 \cdot 10^8$ simulations).

Once a random number u, between 0 and 1, has been generated, it can be used to generate a value of the desired random variable with a given distribution. A common method is the inverse transform method. Using the cumulative distribution function $F_X(x)$, the random variable would then be given as:

$$x = F_X^{-1}(u) \quad (3.15)$$

To calculate the failure probability, one perform N deterministic simulations and for every simulation checks if the component analysed has failed (i. e. if $g(X) < 0$). The number of failures are N_F, and an estimate of the mean probability of failure is:

$$P_{F,MCS} = \frac{N_F}{N} \quad (3.16)$$

An advantage with MCS, is that it is robust and easy to implement into a computer program, and for a sample size $N \to \infty$, the estimated probability converges to the exact result. Another advantage is that MCS works with any distribution of the random variables and there is no restrictions on the limit state functions.

However, MCS is rather inefficient, when calculating failure probabilities, since most of the contribution to P_F is in a limited part of the integration interval.

3.3.2 Monte Carlo Simulation with Importance Sampling (MCS-IS)

MCS-IS is an algorithm that concentrates the samples in the most important part of the integration interval. Instead of sampling around the mean values (MCS), one chooses to sample around the most probable point of failure (MCS-IS). This point, called MPP, are generally evaluated using information from a FORM / SORM analysis (see 3.3.3 below). This algorithm is not included in this release of ProSINTAP.

3.3.3 First/Second-Order Reliability Method (FORM / SORM)

FORM / SORM uses a combination of both analytical and approximate methods, when estimating the probability of failure.

First, one transforms all the variables into equivalent normal variables in standard normal space (i. e. with mean = 0 and standard deviation = 1). This means that the original limit state surface $g(x) = 0$ then becomes mapped onto the new limit state surface $g_U(u) = 0$.

Secondly, one calculate the shortest distance between the origin and the limit state surface (in a transformed standard normal space *U*). The answer is a point on this surface, and it is called the most probable point of failure (MPP), design point or β-point. The distance between the origin and the MPP is called the reliability index β_{HL}. In general, this requires an appropriate non-linear optimisation algorithm. In ProSINTAP, a modified Rackwitz & Fiessler algorithm is chosen. It works by "damping" the gradient contribution of the limit state function and this algorithm is very robust and converge quite fast for most cases.

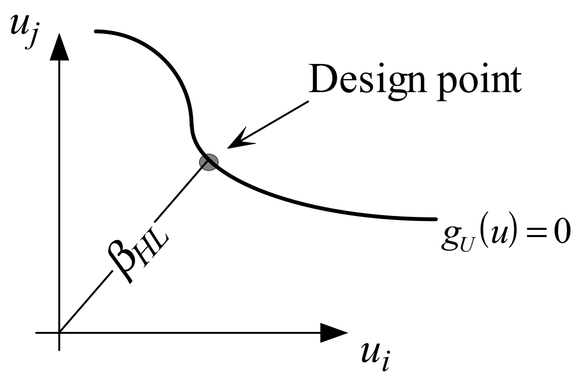

Figure 3.1. The definition of design point and reliability index β_{HL}.

Then, one calculate the failure probability using an approximation of the limit state surface at the most probable point of failure. Using FORM, the surface is approximated to a hyperplane (a first order / linear approximation). SORM uses a second order / quadratic approximation to a hyperparaboloid.

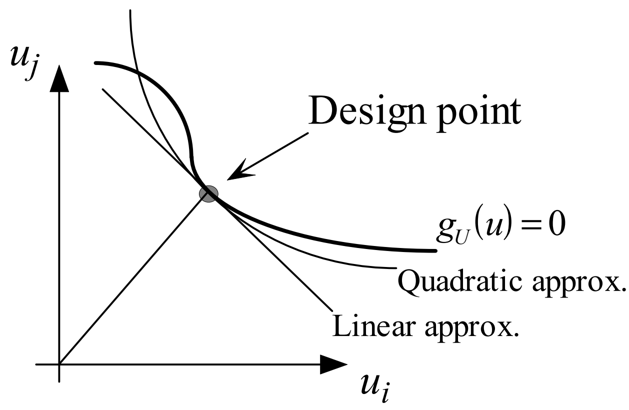

Figure 3.2. Schematic difference between a linear and a quadratic approximation of the limit state surface.

The probability of failure is given as:

$$P_{F,FORM} = \Pr\left[g_{Linear}(u) < 0\right] = \Phi(-\beta_{\mathrm{HL}}) \tag{3.17}$$

$$P_{F,SORM} = \Pr\left[g_{Quadratic}(u) < 0\right] \approx \Phi(-\beta_{\mathrm{HL}}) \cdot \prod_{i=1}^{N-1} \left(1 - \kappa_i \cdot \beta_{\mathrm{HL}}\right)^{-1/2} \tag{3.18}$$

$\Phi(u)$ is the cumulative distribution function in standard normal space and κ_i`s are the principal curvatures of the limit state surface at the most probable point of failure (MPP).

FORM / SORM are, as regards CPU-time, extremely efficient as compared to MCS. Using the implementation within ProSINTAP, you get quite accurate results for failure probabilities between 10^{-1} to 10^{-15}. A disadvantage is that the random parameters must be continuous, and every limit state function must also be continuous. SORM is not included in this release of ProSINTAP.

3.4 Sensitivity factors

Within ProSINTAP, no formal sensitivity analysis is done. However, simple sensitivity factors are calculated when using FORM. These sensitivity factors use the most probable point of failure (MPP) in standard normal space.

3.5 Partial safety factors

Within ProSINTAP, it is possible to estimate partial safety factors, given an assumed target failure probability and characteristic values for fracture toughness, yield strength, tensile strength and defect depth.

4. VALIDATION

To validate the procedure and the program ProSINTAP, comparison was made against two different computer programs:

- STAR6 from Nuclear Electric, calculates the probability of failure using a combination of analytical and numerical integration.
- SACC from SAQ Kontroll AB, used to validate the deterministic parts of ProSINTAP.

Also, a comparison among the different numerical algorithms within ProSINTAP was made.

4.1 Deterministic validation

To check the deterministic parts of ProSINTAP, a comparison was made against the computer program SACC from SAQ Kontroll AB. SACC contains several options, for this validation a fracture assessment procedure based on the R6-method was used.

The following parts of ProSINTAP was validated:
- For the geometry ”a plate with a finite surface defect”, the calculation of K_I, K_r, L_r, stress distribution fit and critical crack size was checked.
- For the geometry ”a plate with an infinite surface defect”, the calculation of K_I, K_r, L_r and critical crack size was checked.
- For the geometry ”a cylinder with a part circumferential internal surface defect.”, the calculation of K_I, K_r and L_r was checked.

For all cases, there were an excellent agreement between ProSINTAP and SACC.

4.2 Validation with normally distributed parameters

To check the probabilistic parts of ProSINTAP, a comparison was made against the computer program STAR6 from Nuclear Electric. First a validation using normally distributed parameters was made.

Two different cases were investigated:
- P_F as a function of primary membrane stress, using two different values of standard deviation for the dominating parameter sizing probability.
- P_F as a function of standard deviation for the dominating parameter sizing probability, using two different values of primary membrane stress.

4.2.1 Probability of failure as a function of primary membrane stress

The following data was used for this validation:

- Probability of failure, defect size given by NDT/NDE was analysed, using the following algorithms:
  - First-Order Reliability Method (FORM).
  - Simple Monte Carlo Simulation (MCS).
  - Monte Carlo Simulation with Importance Sampling (MCS-IS).
- The STAR6 geometry ”extended edge defect in a plate under tension” was chosen.
- Fracture toughness, mean = 200 MPa√m and standard deviation = 10 MPa√m.
- Yield stress, mean = 350 MPa and standard deviation = 30 MPa.
- Ultimate tensile stress, mean = 500 MPa and standard deviation = 30 MPa.
- Defect size given by NDT/NDE, for two different NDE procedures:
  - An advanced NDE procedure, mean = 26,0 mm and standard deviation = 6,5 mm.
  - A bad NDE procedure, mean = 30,2 mm and standard deviation = 18,1 mm.

In figure 4.1, one can find the result using an advanced NDE procedure.

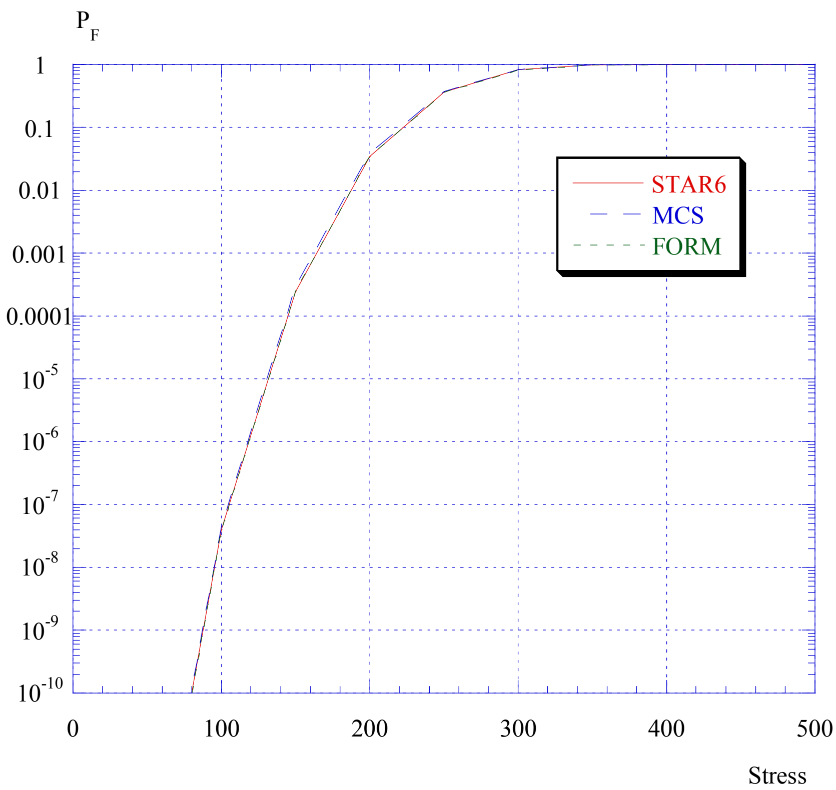

Figure 4.1. Probability of failure as a function of primary membrane stress, using an advanced NDE procedure

For both cases (the result using a bad NDE procedure is not shown), there were an excellent agreement between ProSINTAP and STAR6.

4.2.2 Probability of failure as a function of sizing standard deviation

The main data used was the same as in 4.2.1 above. The difference was that this time one calculated the probability of failure as a function of standard deviation for the dominating parameter sizing probability, using two different values of primary membrane stress (150 and 200 MPa). The results can be found in figure 4.2 below.

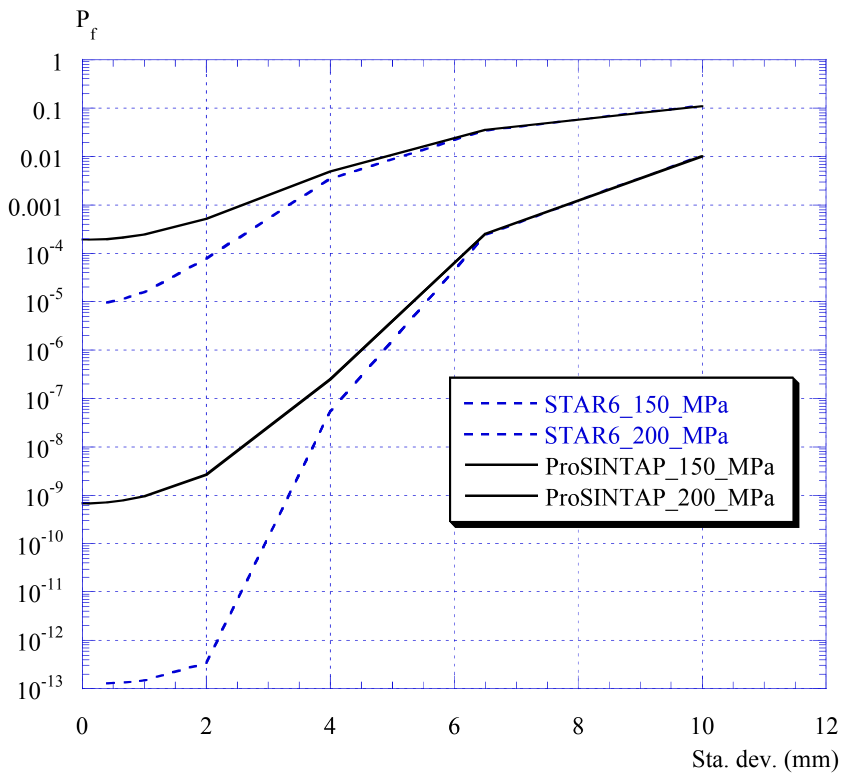

Figure 4.2. Probability of failure as a function of standard deviation for the dominating parameter sizing probability, using two different values of primary membrane stress

As shown in figure 4.2, the agreement between ProSINTAP and STAR6 is very bad for small values of sizing standard deviation. After investigating this difference, it was shown that the results from ProSINTAP was correct, and that the algorithms used in STAR6 was not intended to work for a general problem, when the standard deviation is either ”small” or ”large”.

4.3 Validation with non-normally distributed parameters

The main data used was the same as in 4.2.1 above. The difference was that this time one calculated the probability of failure using an exponential sizing probability (with two different mean values). The results can be found in figure 4.3 below.

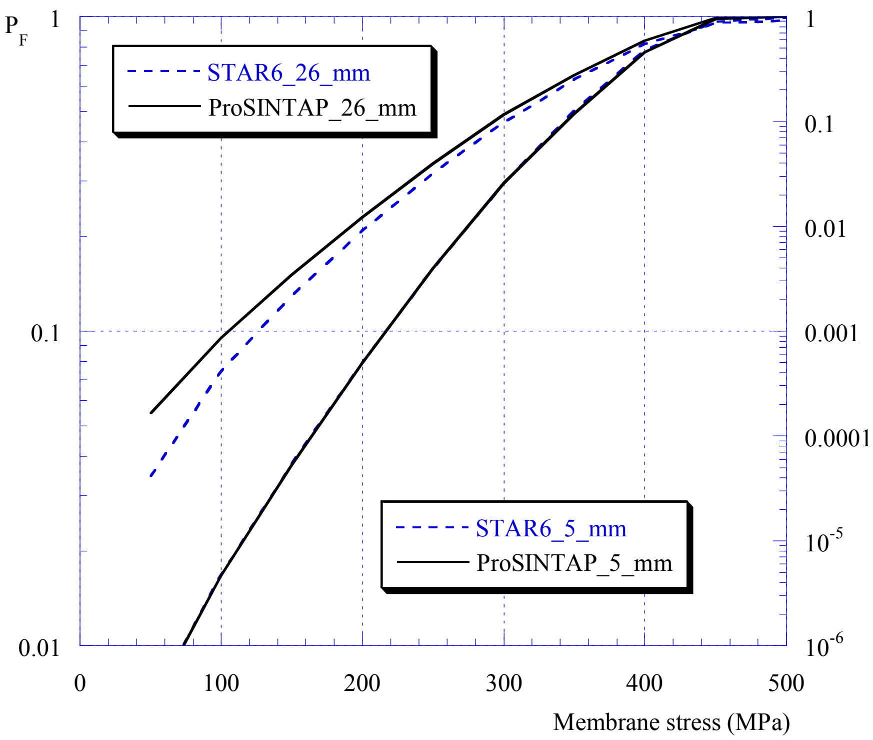

Figure 4.3. Probability of failure using an exponential sizing probability, with two different mean values

As shown in figure 4.3, the agreement between ProSINTAP and STAR6 is very bad for the case with a large mean value (and also a large standard deviation). After investigating this difference, it was shown that the results from ProSINTAP was correct, and that the algorithms used in STAR6 was not intended to work for a general problem, when the standard deviation is either ”small” or ”large”.

4.4 Validation of a case with secondary stresses

The main data used was the same as in 4.2.1 above. The difference was that this time one calculated the probability of failure as a function of applied secondary membrane stress. The results can be found in figure 4.4 below.

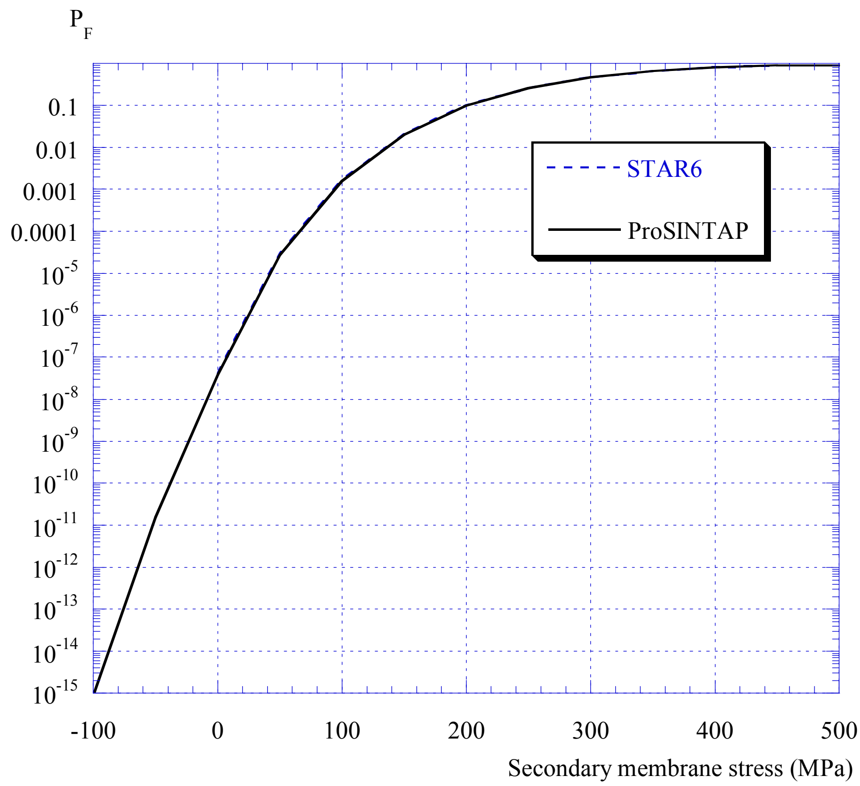

Figure 4.4. Probability of failure as a function of applied secondary membrane stress

As shown in figure 4.4, the agreement between ProSINTAP and STAR6 is excellent in this case, using a simple ρ definition for the validation exercise only.

5. CONCLUSIONS

Within SINTAP, Sub-Task 3.5, a probabilistic procedure has been developed by SAQ Kontroll AB to calculate two different failure probabilities, P_F:

- Probability of failure, defect size given by NDT/NDE.
- Probability of failure, defect not detected by NDT/NDE.

Using the procedure, SAQ Kontroll AB has also developed a computer program ProSINTAP. This program can also be used to estimate partial safety factors, given an input target failure probability and characteristic values for fracture toughness, yield strength, tensile strength and defect depth.

Extensive validation has been carried out, using the computer programs STAR6 from Nuclear Electric and SACC from SAQ Kontroll AB.

ACKNOWLEDGEMENT

The development of ProSINTAP has been financially funded by BRITE-EURAM project No. BE95-1426 and SAQ Kontroll AB. Their support has made the program possible and is greatly appreciated.

The project manager of the development of ProSINTAP, Peter Dillström, wishes also to express his gratitude to the other members of the development team; Björn Brickstad, Carl von Feilitzen and Weilin Zang at SAQ Kontroll AB in Sweden, Prof. Kim Wallin at VTT in Finland, Prof. Fred Nilsson at the Royal Institute of Technology in Sweden and also to Dr. Ray Wilson at Magnox Electric in England for assisting with the validation.